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Using Science Misconceptions for Developing Critical Thinking in Learners and Teachers

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USING SCIENCE MISCONCEPTIONS FOR DEVELOPING CRITICAL THINKING IN LEARNERS AND TEACHERS

A Thesis Presented

by

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ABSTRACT

USING SCIENCE MISCONCEPTIONS FOR DEVELOPING
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Students' poor interest and academic achievement in science as well as their inability to master situations in their everyday life seem to be related to their lack of skills in critical and creative thinking. However, teaching such skills within both primary and secondary curricula is not mandatory. The consensus is much more toward teaching thinking skills through content than as a separate course. In this thesis the conflict between students' prior conceptions about the natural world and scientific concepts is viewed as a resource for teaching thinking skills. A review of the literature on science misconceptions in mechanics suggests that science misconceptions are the product of students' active constructions as students try to make sense of the information given to their sensory system. In addition, the knowledge acquired from science classes is not passively incorporated in students' minds. Both points are supported by the constructivist epistemology and cognitive psychology.

Analogical reasoning and concept mapping are two instructional metacognitive strategies designed to deal with students' misconceptions to bring about conceptual change in the learner. This process involves the replacement of the learner's previous knowledge by the scientific view through a process of awareness of one's starting conceptions and evaluation of their consistency with evidence. This implies possessing the ability of making shifts from one context to another, such as from the science classroom environment to everyday life. In this thesis both strategies are also seen as a means to engage learners in a metacognitive process through the organization and reflection of their beliefs, making them explicit and available to themselves, teacher and peers using dialogical thinking. Those strategies are very effective in promoting the development of skills in critical and creative thinking using multiple frames of reference. The conclusions draw attention to the important role played by teachers within the new constructivist perspective of learning, and to the need to integrate school science and technology using teacher creativity to enhance the science curriculum and promote meaningful learning. They also provide some suggestions for future work to explore the viability of using science misconceptions to develop critical and creative thinking skills.

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CHAPTER I

INTRODUCTION

General Overview

During the past two decades, research in the field of science education has shown that students come to science classes with their own theories about the natural world derived from their personal experience. This outcome is consistent with the constructivist model of knowledge, the current epistemology adopted in most of the studies dealing with students' previous understandings about the natural world (Duit 1993, Driver 1985, McDermott 1990, Novak 1987). On the latter view, learners attempt to make sense of the natural world by establishing links between their old and new experiences. Moreover knowledge is not viewed as something transmitted directly from the teacher to the learner without any transformation. On the contrary, all information input to an individual's sensory functions is interpreted in his/her* mind before being incorporated in his cognitive structure. This is the philosophical aspect of the individual's acquisition of knowledge. There is a concordance between this philosophical view and cognitivism, where knowledge is an attribute of the individual's mental activities.

The findings from studies done on students' science conceptions have shown that most of the time students' views are incompatible with the scientific view and can be labelled science misconceptions. For example, students' prior ideas about motion and force usually are in disagreement

* From now on the genders will be used alternately.

with Newtonian mechanics. Another important finding concerns the influence such misconceptions exert in the learning process once they are deeply rooted in the student's cognitive structure.

Parallel to the study of science misconceptions, a great deal of attention has been directed to the issue of teaching thinking skills. It seems that there is a consensus that students' poor academic achievement in science and math as well their inability to master situations faced in their everyday life is a consequence of their lack of ability to think critically and creatively. Considering these two issues together, i.e., students' science misconceptions and students' lack of skills in critical and creative thinking, I propose in this thesis to explore the viability of teaching thinking skills using students' science misconceptions. Improving students' abilities and skills in thinking critically and creatively should in turn enable them to find the gaps between their understandings of the natural world and the scientific laws, principles and theories on the topic being studied. This will support the achievement of a conceptual change in the student's cognitive structure, which, according to West and Pines (1985) evolves when the learner is aware of its necessity. For that there is a special need to use well designed instructional strategies that help students learn how to learn and how to think about their own thinking.

Analogical reasoning (Clement 1987, Brown and Clement 1989) and concept mapping (Novak and Gowin 1984) are two instructional strategies suggested and applied in the studies dealing with science misconceptions. Both of them have been used to help teachers and learners overcome science misconceptions and promote desirable conceptual change in students' systems of beliefs through a process of self awareness. In addition, these two instructional strategies serve as a means to engage students in a peer group discussion, i.e., dialogical thinking which fosters the development of critical and creative thinking. This practice also helps to decentralize the traditional authority of the teacher's role within the teaching-learning process. Such a traditional classroom environment prevents students from making their ideas available to the teacher and peers, which I see as an obstacle to the development of thinking skills. Most important is that those two instructional strategies can be used in the design of science lessons exploring the resources presently available, i.e., thoughts, language, students' experiences and systems of beliefs, teachers' experience and creativity, textbooks and so on, to transform the classroom environment into a "community of inquiry" as it is called by Lipman (1987, p. 153).

It is the teacher's responsibility to create an atmosphere in the classroom where students feel they are being challenged and their contribution is highly appreciated and necessary. They need to be encouraged to share their ideas without the fear of making mistakes. But on the other hand, they also need to learn to present their own ideas supported by convincing arguments. This practice can be widely exercised through peer group dialogues where everybody has the opportunity to make their ideas available for reflection, evaluation and criticism. This kind of classroom environment is much more realistic in terms of transforming students into independent thinkers than the traditional one where the teaching-learning process is centered in the teacher and textbook authority. The adoption of this alternative will let students have the opportunity to test their views about the topic being studied by using multiple frames of reference, which means approaching the problem using different viewpoints.

Thesis Organization

This thesis is organized into 7 chapters. Chapter II presents an overview of science misconceptions including a brief historical background about terminology, epistemology and psychological views adopted to support the studies done in this area. One section deals with possible sources of science misconceptions, mainly in mechanics. The final part of the chapter is devoted to a discussion of the positive role science misconceptions can play as a tool to develop thinking skills using multiple frames of reference.

In Chapter III a brief literature review of students' misconceptions about force and motion is presented to show the influences of everyday experiences and language upon the individuals' concept formation as well some similarities with pre-Newtonian theories like the medieval impetus theory and Aristotelian physics.

Chapter IV presents an overview of constructivism, the current epistemology adopted in the research field of science misconceptions. Parallel to the philosophical foundation there is the psychological basis supporting the studies done in this domain. Ausubel's Meaningful Learning Theory (Ausubel 1968) and the Generative Model of Learning (Wittrock 1974, 1978) are the two cognitive learning theories that have been adopted the most in science misconceptions and will be included in this chapter.

Chapter V is concerned with two instructional strategies developed to promote conceptual change in students' system of beliefs, in order to overcome science misconceptions. They are analogical reasoning and concept mapping. These two instructional strategies will serve as a means to engage the students in a peer group discussion, i.e., dialogical thinking which fosters the development of critical and creative thinking using multiple frames of reference.

Chapter VI reports an experience I had in the summer of 1992 when I had the opportunity to participate in a summer project designed for freshmen undergraduate students of the class of 1996 at another university in the Boston area. This project was divided into 4 sections: Math, Physics, Chemistry and Writing. I followed the physics section during its 8 weeks duration. The subject taught was introductory mechanics. The three major goals of this project were: a) to acquaint the students with the rules and philosophy of the institution; b) to help them achieve a basic level in physics; c) to develop thinking skills using their misconceptions in mechanics.

The Afterword will include some claims and suggestions mainly addressed to teachers-in-training as well to teachers-in-service. Some suggestions for future work will also be addressed in this section. A comment concerning the emphasis on critical thinking and the importance of integrating school science and technology in the Project 2061 will close the section.

CHAPTER II

SCIENCE MISCONCEPTIONS

Overview

The wide range of ways each individual sees and understands how the world works has generated incredible discoveries and has built up scientific knowledge throughout the centuries. I believe this heterogeneity is related to differences between the frames of reference that an individual has (Swartz 1987; Paul 1987). I would define frame of reference as a mental entity made up of individuals' values, experiences, and beliefs, functioning as a filter through which all their analyses, inferences and conclusions are made. That is, frame of reference is the device that explains and supports the individual's point of view. This assumption can be illustrated by asking several individuals to narrate the same movie. Many of the narrations, if not most, will differ, presenting peculiarities which are associated with the individual's frames of reference. Indeed it seems to me that the heterogeneity is caused by the distinctiveness of each individual's frames of reference which might be different for the same individual according to the domain adopted. I will be discussing frame of reference in more detail elsewhere in this chapter due to the importance it plays in interpreting and assigning meanings to all phenomena that take place in our lives.

Whereas individuals' diversity in assigning meanings to the natural world is an acknowledged fact, outcomes from studies in the research field of science education have shown a significant degree of homogeneity among students' understandings and beliefs for interpreting and explaining some natural phenomena, both before learning the subject formally or by holding the same beliefs even after having formal instruction. Frequently those ideas differ substantially from the accepted scientific theories.

Since individuals' inferences are made as a function of their frame of reference, this fact makes me suppose that for some reason students sharing some common experiences, i.e., everyday observations, might set their frame of reference in a very similar way when observing any specific natural phenomena, which causes them to come up with the same understandings and conclusions upon that science topic. Examples are that motion implies force which means a force is required to sustain motion (McDermott 1984); that motion and rest are fundamentally inequivalent, so that a stationary object cannot exert a force (Driver 1985); that heavier objects fall faster than lighter ones, so that speed is greater for the heavier object; and that light travels farther in the dark (McDermott 1990).

Fortunately this kind of behavior generates a well defined and small set of beliefs, mainly in mechanics. This makes the design of instructional strategies for dealing with this issue less complex, once they are not considered individuals' idiosyncracies (Hestenes 1987; McCloskey 1983b, Clement 1983). Studies have shown that those sorts of understandings of natural phenomena in mechanics have a certain degree of similarity to the pre-Newtonian theories of motion (14th to 16th centuries) (Halloun and Hestenes 1985; Osborne and Gilbert 1980; Viennot 1979; Caramazza and McCloskey 1984; Thijs 1992; Clement 1982; McCloskey 1983a, b; McDermott 1984).

The intent for this chapter is at first to introduce science misconceptions according to their depiction in the current literature. Thereafter I propose to explore the viability of developing thinking skills, and especially the ability of using multiple frames of reference, through science misconceptions.

Background

Each of us has our own and very individual way of observing and analyzing how things work in the physical world and then coming up with conclusions. Sometimes the model we construct for representing an event does not fit the scientific model, generating what has been commonly called science misconceptions in the research field of science education, as well as in several other research fields related to the teaching-learning process.

Introduction

The intriguing and interesting phenomenon of science misconceptions has been studied steadily over the past two decades world-wide and cross-culturally mainly by cognitive psychologists, science educators, and science instructors. It has been producing new insights for the development of techniques to facilitate the process of teaching and learning science, as well as generating controversial issues such as the origin of concepts individuals possess before formal instruction. That is, are those concepts learned from experience or triggered by it? (Preece 1984). This disagreement seems to be a consequence of different philosophical and psychological theories of knowledge and learning adopted by researchers in the field: rationalism, empiricism and constructivism in philosophy, and behaviorism and cognitivism in psychology.

In the 1920s Jean Piaget (1896-1980) started studies in child psychology having the core of his studies centered in children's understanding of mathematical and scientific topics (Piaget 1951, 1953, 1954). His cognitive developmental theory is the product of all those studies and no one involved in the field of education and cognitive sciences can afford to disregard it. In the 1970s his theory was rediscovered as a consequence of curriculum reform which occurred in the 1960s (Novak 1977).

Terminology: the epistemological and psychological views

The more common designation for this phenomenon has been "science misconceptions," although several other names have been given to it, e.g., "preconceptions" (Novak 1977b), "alternative frameworks" (Driver 1981), "children's science" (Gilbert, Osborn and Fensham 1982), "naive theory" (McCloskey 1983b), "common sense intuition" (Halloun and Hestenes 1985b), "alternative conceptions" (Sequeira and Leite 1991; Hewson and Hewson 1983), "spontaneous reasoning" (Saltiel and Viennot 1984), and "students' conceptions" (Duit 1989, 1993).

These names are associated with the researcher's epistemological view. From the beginning of the 1980s to now the constructivist model of knowledge has been widely adopted in this research field (Driver and Oldham 1986; Bodner 1986; Novak 1985, 1987, 1989; Wheatley 1991; Fischer and von Aufschnaiter 1993; Duit 1993). According to the constructivist perspective, knowledge is actively constructed in the individual's mind as an attempt to make sense of her experiences with the physical and social environment. This view supports the position of a group of researchers who see students' ideas about science as an alternative view instead of considering them a wrong or false conception compared with the scientific view. These researchers have replaced the term "science misconceptions" by "alternative frameworks," "spontaneous reasoning," and so on.

Constructivism opposes other epistemologies such as rationalism and empiricism developed in the 17th and 18th centuries. While the empiricists' view (Locke 1956) assumes that knowledge is the product of sensory experience with the mind of each human a blank slate, tabula rasa at birth, rationalists associated knowledge with innate ideas, arguing that true knowledge comes from reason (Kamii 1979).

As important as the epistemological theories is the psychological model of learning adopted by the researcher. Undoubtedly at the present time cognitivism is ascendent, while behaviorism started fading away in the 1950s and 1960s at the start of the cognitive revolution. Within a behaviorist framework, the process of learning is associated with the formation of habits through a mechanical process of reinforcement without any conscious and rational activity. In contrast, within a cognitive framework, the basis for learning lies in the use of information acquired from past experiences stored in the brain to generate solutions through a process of reflection and awareness.

Based on the cognitive model of learning are both the generative learning model (Wittrock 1974) and the meaningful learning model (Ausubel 1968) which have been adopted in the studies related to science misconceptions. The former focuses on the notion of transfering prior ideas to solve a new problem, i.e., learners are supposed to generate relevant relations between information and experience. According to Wittrock its fundamental premise is "that people tend to generate perceptions and meanings that are consistent with their prior learning" (1974, p.88) and "according to the model, to learn with understanding a learner must actively construct meaning." (Osborne and Wittrock 1983, p. 493) According to Novak (1985), Wittrock has developed this model based on some of Ausubel's earlier ideas such as the meaningful learning model. Ausubel explain that

> meaningful learning takes place if the learning task can be related in nonarbitrary, substantive (nonverbatim) fashion to what the learner already knows, and if the learner adopts a corresponding learning set to do so. Rote learning, on the other hand, occurs if the learning task consists of purely arbitrary associations, as in paired-associate, puzzle-box, maze, or serial learning; if the learner lacks the relevant prior knowledge necessary for making the learning task potentially meaningful; and also (regardless of how much potential meaning the task has), if the learner adopts a set merely to internalize it in an arbitrary, verbatim fashion (that is, as an arbitrary series of words). (Ausubel 1968, p. 24)

Despite all the recent attention centered around cognitive frameworks and models, recent studies in neuropsychology (Petri and Mishkin 1994) have shown the possibility of a two-system model combining elements from both the cognitive and behavioral perspectives. The acquisition and retention of memories and experiences is related to the cognitive system (the system that stores memories), and the acquisition of habits to the noncognitive system (the system that develops habits). Thus, both systems may operate in the human mind depending upon what is being learned.

It seems to me "spontaneous reasoning," "preconceptions," and "alternative frameworks," represent the students' beliefs about natural phenomena prior to formal instruction received at school. This is the prescholastic knowledge (Gardner 1991), which may or may not be in disagreement with the scientific model. "Science misconceptions" is a broader term used for designating students' beliefs, before or after formal instruction, which conflict with the scientific view. In any case, until now there has been neither agreement on the terminology by researchers in the study of this phenomenon, nor on the criteria used for evaluation of the data, nor a common goal of what to do with the findings.

Physics: the main focus and the major findings

Physics has been the science domain most explored by researchers, followed by biology and chemistry. Table 2.1 (Duit 1987, 1993) shows how the studies in this research field are distributed. Topics like light, heat, temperature, mechanics, electricity, have been extensively studied by different investigators. While no agreement exists upon the terminology used to designate the phenomenon of misconceptions, the findings of these studies have been similar in a number of respects. These include: (1) replications of common misconceptions suggesting a recognizable pattern among students' views in some topics in physics (mainly mechanics) (McDermott 1984, 1990; McCloskey 1983b; Driver 1989; Caramazza, McCloskey and Green 1981; Clement 1983; Solomon 1983); (2) finding these misconceptions are very resistent to change, i.e., they are deeply incorporated in the students' cognitive structure (Clement 1983; Treagust 1988; Driver and Oldham 1986; Solomon 1983); (3) showing there is some tendency for students to replicate scientific ideas held by scientists and philosophers in the past, e.g., medieval impetus theory (McCloskey 1983b; Clement 1983), vitalist conceptions of energy (Preece 1984), some of Aristotelian physics (McCloskey 1983b; Halloun and Hestenes 1985b); (4) and finally, as a consequence of the three former findings, showing that science misconceptions seem to create some constraints in the teaching-learning process (McCloskey 1983b; McDermott 1984), that is students

Table 2.1 Studies on students' conceptions in different content areas (based on information in Pfundt & Duit 1987, 1993)

GENERAL AREAS	NUMBER OF STUDIES up to 1987	NUMBER OF STUDIES up to 1993	SPECIFIC TOPICS
MECHANICS	176	343	force and motion; work, power, energy; speed,acceleration; gravity; pressure; density; floating; sinking
ELECTRICITY	104	181	simple, branched circuits; topological and geometrical structure; models of current flow; current, voltage and resistance; electrostatics electromagnetism; danger of electricity
HEAT	47	68	heat and temperature; heat transfer; expansion by heating; change of state, boiling, freezing; explanation of heat phenomena in the particle model
OPTICS	40	90	light; light propagation; vision; color
PARTICLES	39	103	structure of matter; explanation of phenomena (e.g. heat, states of matter); conceptions of the atom; radioactivity
ENERGY	27	89	energy transformation; conservation; degradation
ASTRONOMY	19	46	shape of the earth; characteristics of gravitational attraction; satellites
"MODERN" PHYSICS	5	28	quantum physics; special relativity
CHEMISTRY	56	194	combustion; oxidation; chemical reactions; transformations of substances; chemical equilibrium; symbols, formulas; mole concept; electrochemistry
BIOLOGY	40	274	plant nutrition; photosynthesis; osmosis; life; origin of life; evolution; human circulatory system; genetics; health; growth

Source: Duit 1987, 1993

try to adapt the new understandings acquired from the science lessons at school to their previous knowledge on that subject. Clement concluded, "it therefore appears to be a major stumbling block in the physics curriculum." (1983, p. 326)

The trends throughout the 70s, 80s and 90s

The main focus of studies done in the research field of science misconceptions in the 1970s was to find out about students' beliefs. What were the conceptions and understandings they held about gravity, force, energy, light, etc.? Clinical interviews, think-aloud protocols, multiple choice tests, and open-ended questions were the most common procedures used for assessing students' thinking and understandings about those science topics before and after having formal instruction in them.

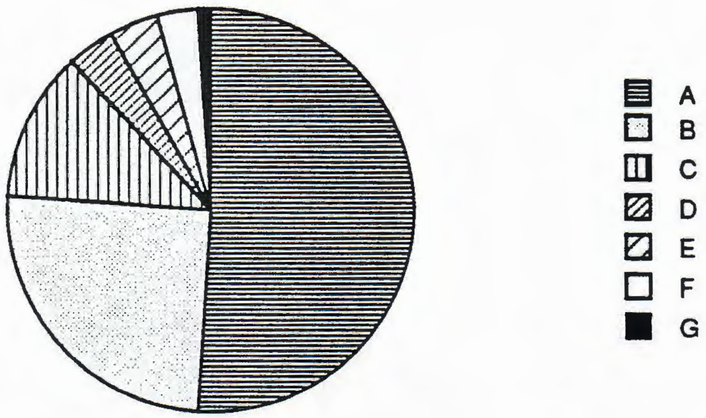
There was a lack of studies concerning the design of pedagogical methodologies and instructional strategies for dealing with misconceptions by promoting the desirable conceptual change in the students' mind. A few works were done intending to turn students' science misconceptions into a valuable source for the design of science lessons where the development of skills in higher order thinking and creativitiy would be perfectly well fitted.

In the 1980s the research community involved directly or indirectly with the teaching-learning process like cognitive psychologists, philosophers, educators, science teachers, and curriculum developers, began to investigate issues like novice-expert shift in adults (Carey 1985), the development of theories on mental models (Gentner and Stevens 1983), and the power of computers (Papert 1980). Parallel to these studies, there was a major stream of work aiming at the development of higher order thinking skills and creativity (Paul 1990; Baron and Sternberg 1987, Lawson 1980). The development of pedagogical strategies to deal with the previous knowledge students bring to science classes (Hestenes 1985; Bodner 1986; Minstrell 1982; Clement 1988; Novak 1984) began to be part of the focus of the studies on science misconceptions as well.

Seminars (Novak 1987, 1993; Archenhold, Driver, Orton and Wood-Robinson, 1979; Lijnse 1984), the AETS Yearbook (Lawson 1980) and books (West and Pines 1985; Adey, Bliss, Head and Shayer 1989; Papert 1980), presenting a wide range of studies in the area of science and mathematics related with cognitive theory of development and constructivist theory of knowledge, were major contributions for the research field of science misconceptions in the 1980s. Studies focusing on instructional strategies for dealing with students' science misconceptions and the development of pedagogical methodologies aiming at the development of meaningful learning (Ausubel 1968) started increasing compared to the studies done in the 1970s.

Duit (1987,1993) has maintained an updated bibliography (Pfundt and Duit 1987, 1993) on science misconceptions since 1977. By 1987 that bibliography was composed of about 1000 entries. Of those works, the number of studies concerning the development of instructional strategies and pedagogical methodologies for dealing with students' science misconceptions was around one fifth of the studies about students' beliefs and understandings on the different topics in science. By 1993, this bibliography had expanded to 3,000 entries (2800 excluding 1993), and the number of studies dealing with students' conceptions represents around 50% of all studies done in the research field, but still a relatively small percentage investigated instructional strategies. The other 50% are distributed according the following classification adopted by Duit (1993) in Fig. 2.1.

From the end of the 1980s to now the studies on students' understandings in science still predominate over the studies aiming at the development of new techniques, strategies and pedagogical methodologies



A Empirical investigations of students' conceptions (details on Tab. 2.1)
B General (theoretical) considerations concerning research in this field
C Studies on new teaching and learning approaches taking students' conceptions into account
D Empirical investigations of teachers' conceptions
E Empirical investigations of students' and teachers' conceptions of teaching and learning
F Empirical investigations of students' and teachers' conceptions of science
G New approaches to teacher education

Fig. 2.1 Distribution of research related to science misconceptions in different areas up to 1993 (Duit 1993)

in the teaching-learning process using science misconceptions as the foundation. By the same token we can see that the last kind of research is flourishing and has significantly increased in this period as shown in Fig. 2.2 (Duit 1993).

However, this is not sufficient to promote significant and desirable change by supporting and guiding a new practice of research upon pedagogical methodologies in this area. A sound definition of science misconceptions or other equivalent terms used to label this phenomenon--

now more than ever accepted and recognized as being a pattern among students-- is still missing (Novak 1987).

In my opinion one of the causes for this situation is the lack of interaction among the different categories of investigators: cognitive

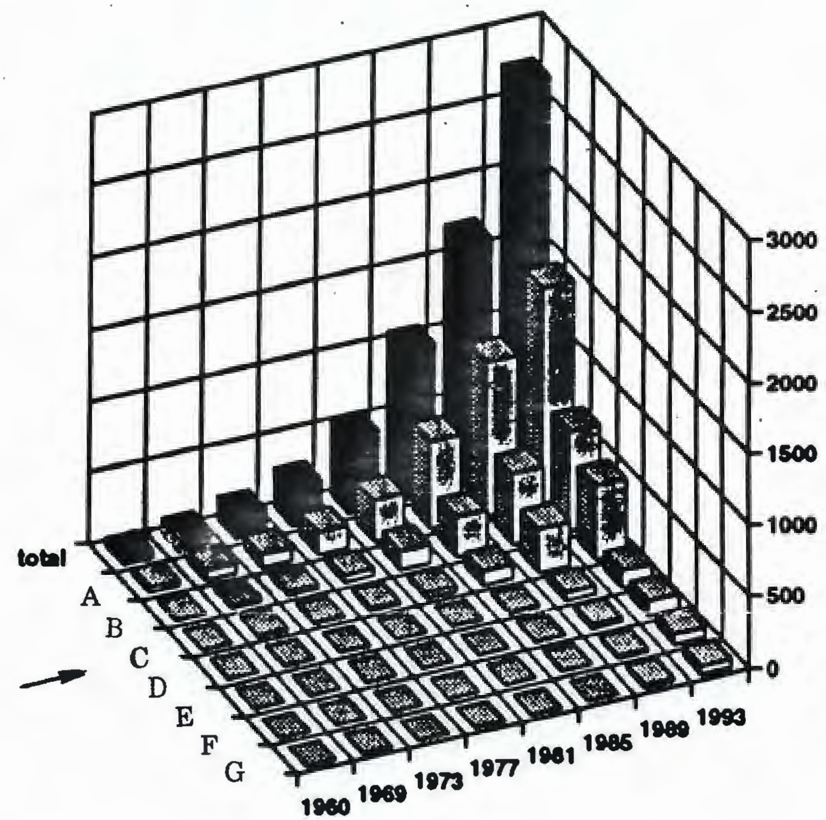


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Fig. 2.2 The increase of number of studies about educational strategies for dealing with science misconceptions - (C) (Duit 1993)

psychologists, educators in general, faculty, science teachers at all levels, philosophers, etc. Their investigations have the same content designed for different contexts. Therefore the criteria used in the evaluation and appraisal of the data differ substantially in order to target their specific aims. As noted by McDermott (1990) cognitive psychologists, science educators and physics instructors have the core of their investigations targeting different aspects. The cognitive psychologists quite likely will have their interest centered in the development of theoretical mental models of human cognition, e.g., the study of the novice-expert shift using the technique of problem-solving (Carey 1985; Wiser and Carey 1983). Science educators probably will be using the findings of their research on curriculum design, development of general instructional strategies bearing on the pedagogical and didactic aspects of the teaching-learning process. The physics instructors will be concerned with students' specific difficulties in that specific topic and the information obtained from their investigation is probably used to improve the teaching-learning process.

The scientific community in charge of teaching science at the secondary, undergraduate and graduate levels, as well as educators, psychologists and philosophers, should join efforts towards a new practice in the area of research in science education. This practice concerns mainly the development of instructional strategies taking into account students' previous understandings about the natural world, instead of just cataloguing their ideas.

Possible Sources for Science Misconceptions

It is a natural process when studying a phenomenon to identify the causes related to it. This will provide the investigators with a better understanding and consequently help them in the development of a sound and clear theory about the phenomenon. This stage is fundamental for the development and design of strategies and techniques to deal with possible constraints the phenomenon is causing within its context.

This is the case of science misconceptions. Once the phenomenon has been identified and recognized as being a possible factor affecting the teaching-learning process of learning mechanics, the next step is to find out the causes of it. They will be the foundation for the design of instructional strategies and techniques to overcome students' misconceptions in that topic as well the development of skills in critical and creative thinking and vice-versa.

Language, symbolism and terminology

From birth human beings interact with the external world through the amalgam of both sensorimotor and symbolic ways of knowing (Gardner 1991) and start constructing theories about the world. No doubt language plays an important role in this process giving to human beings the necessary freedom to convey their thoughts, express their emotions, and attribute meanings to things. Vygotsky stated that "a word without a meaning is an empty sound, no longer a part of human speech." (1991, p. 6)

We are linguistic creatures (Gardner 1991) and it is well known that little children exposed to more than one language can be at least bilingual without any extra effort. For example my five-year-old daughter Maria Carolina, who speaks English and Portuguese fluently without being taught, has been raised in both a Portuguese environment at home and an English one out of the home. I know at least a dozen children in the same condition.

By the same token, if the person does not have the ability and skills to move from one context to another aware of the content being used in each of them, language can produce constraints and burdens regarding the formation of concepts. It seems to me this process is associated with frame of reference, because a word is associated to a meaning (Vygotsky 1991) and a meaning varies according to the frame of reference adopted. To illustrate this assumption let us consider the following situation: if a person in a computer lab without any acquaintance with computers hears the phrase: "Please, give me the mouse," this will appear to her a wacky and nonsense idea, although the word "mouse" is part of her vocabulary. Herron (1984) gives a similar example with the word "apple" being used in a grocery and in a computer store.

Mathematics, physics, chemistry, philosophy, etc. have their own symbolism, which means their own language, and I believe herein lies one of the sources of misunderstandings giving rise to science misconceptions. Usually the everyday language and the scientific language share the same words, but not the same meaning. In physics the word "acceleration" includes the following meanings: speeding up, slowing down and changing direction while in the everyday language it means just speeding up (Duit 1985).

The word "force" is another example. Usually the everyday meaning associated with the word "force" is related to physical activities, pulls and pushes, and muscular exertion. Therefore force is conceptualized as an ability of living things and/or moving things like cars, planes, drills, and so forth. The fact that students experience difficulty in admiting that an inanimate object like a table exerts a force toward a book at rest on it (Minstrell 1983) might be associated with this everyday notion of force. Besides the words "force" and "power" are interchangeable in their everyday meaning as in the sentences "she has the power," "the crane has enough force to lift that rock," while in physics they are not.

In the summer of 1992, I had an opportunity to follow for eight weeks a group of college freshmen attending a physics course. The main goal of that course was to get students acquainted with their new academic environment, and have them achieve a basic level in mechanics. The director of this summer project was very interested in issues related to critical and creative thinking and science misconceptions. As a result of our discussions, he proposed an activity to the students that offered them an opportunity to express their conceptual understanding about specific words used in mechanics and everyday life.

The proposed assignment was to write a paragraph using three words taken from the lesson taught that week, and three words from the lesson to be presented the following week. "Dimension," "space," and "time" were the words of the first week, and "speed," "velocity," and "acceleration" those of the second week. The presence of everyday meaning for these words was detected and will be briefly discussed in chapter VI. In short, the role of everyday language in the formation of concepts about the physical world is very strong. In my view it is one of the causes of the persistence of science misconceptions.

<u>Environment, everyday observations and scientific theories</u>

According to Newtonian mechanics, a body will continue to move in a straight line at constant speed or it will stay at rest if no force is exerted on it. This conflicts with everyday observations. When a boy gives a push on his toy fire truck he observes the truck moving a few inches and then stopping. Most likely he will justify saying that the truck stopped because the force he applied "died away." This concurs with the impetus theory, which will be discussed in Chapter III. If I need to move my sofa I need to push it, which means I need to apply a force to it. When it reaches the desired position, I stop pushing and it stops. Those objects do not behave according to what was stated in the first paragraph, i.e., like a Newtonian object. Therefore there is conflict between the ideal theory, i.e., classical mechanics and everyday observation (Papert 1980).

And what about everyday experiences with falling objects? The ideal theory states that at a particular point on the surface of the earth with no air resistance, all bodies fall with equal acceleration, regardless of shape and density. Everyday experiences suggest something different. A piece of paper or a piece of foam is going to fall slower than a metal spoon or a stone, for example. Even a sheet of paper will fall differently depending upon whether it is flat or crumpled up.

I believe that language and everyday observations are the two major sources for generating science misconceptions. Individuals start building their knowledge about motion, for example, based on these factors. They develops and construct their own theory which usually is much closer to Aristotelian physics than to Newtonian physics. The former is closer to everyday observations; the latter is ideal theory. It is much more complex and needs very sharp and deep reflection (i.e., the use of creativity and higher order thinking) in order to see beyond the commonplace of everyday experiences and to create imaginary situations which cannot be confirmed by everyday experience but will prove the inconsistency of the prior theory.

Critical Thinking, Creativity and Science Misconceptions

I assume that scientific theories are the by-product of creative and critical thinking minds. Further I believe that paradigm shifts such as the shifts from Aristotelian physics to Newtonian physics to the Einstein theory of relativity are associated with frame of reference. The new theories and discoveries are a matter of looking at the old experiences with a different frame of reference, and then coming up with new inferences and conclusions.

Throughout the literature review I have done in the area of science education focused on science misconceptions I could not find a variety and significant number of studies establishing hypotheses about the link between science misconceptions and critical and creative thinking, at least explicitly. However, I can see a very strong interrelationship between the phenomenon of science misconceptions and the development of the skills of critical and creative thinking.

"Recycling" is one of the most fashionable words at the present time, and what I propose is a form of recycling science misconceptions. In particular, I propose to explore students' misconceptions in order to develop the skills of critical and creative thinking in both learners and teachers. Further, I then propose to use those new critical and creative thinking skills to overcome science misconceptions through a process of self-conscious reflection. Learners will follow all the steps from the first one in which the misconception is made explicit to the last one when they will be able to compare their naive and scientific knowledge on that topic. The misconceptions students bring with them to science classes must be recycled and transformed into a powerful instrument to promote desirable conceptual change in that science topic.

Fig. 2.3 represents my view of the recycling of science misconceptions into the skills of critical and creative thinking. This view includes frame of reference, a key element in this process, since each meaning attributed to the natural world is caused by the peculiarity of each individual's frame of reference, i.e., the lens through which she sees the world.

Furthermore to think critically and creatively means to be aware of the different ways a phenomenon can be seen, which means to possess the ability to make shifts from one frame of reference to another. This fluidity should enhance student's ability to come up with much more sound and accurate inferences, conclusions and decisions.

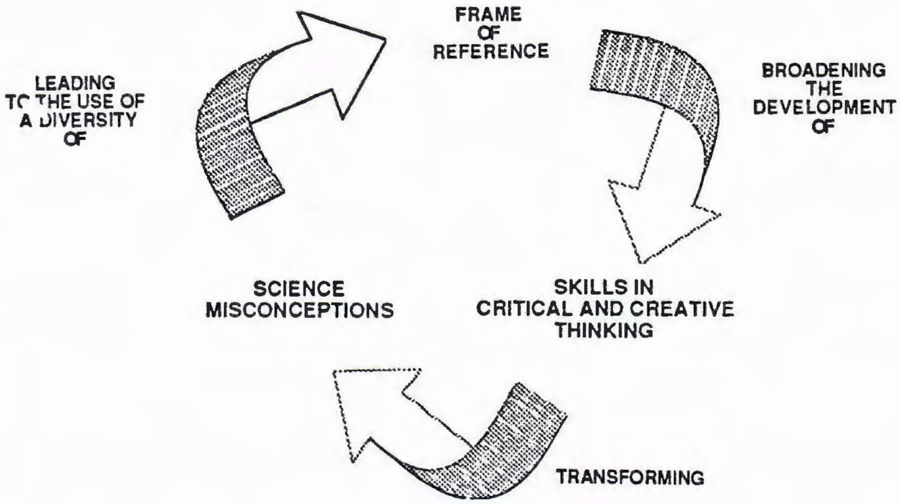
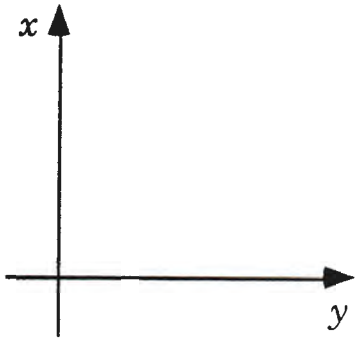


Fig. 2.3 Recycling science misconceptions into critical and creative thinking skills through frame of reference

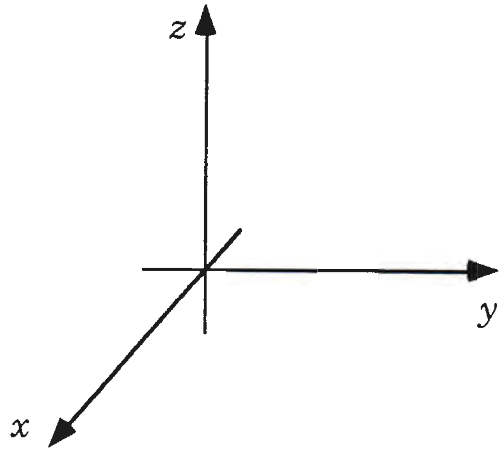
Frame of reference

For an individual who has background in mathematics and/or physics, the expression "frame of reference" at first will be associated with the rectangular coordinate system or Cartesian coordinates in the plane or in space, both shown in Fig 2.4, not to mention the polar, spherical and cylindrical systems of coordinates, etc. Frame of reference within this context has the purpose of characterizing the element being studied. It gives to the element particular properties within which it can be described and analyzed.

Particularly in physics, the concept of frame of reference is associated with position and movement, i.e., a suitable coordinate system within which any natural phenomena can be observed, measured and described by an individual. As an example, the position of a boy in a



(a) Plane coordinates

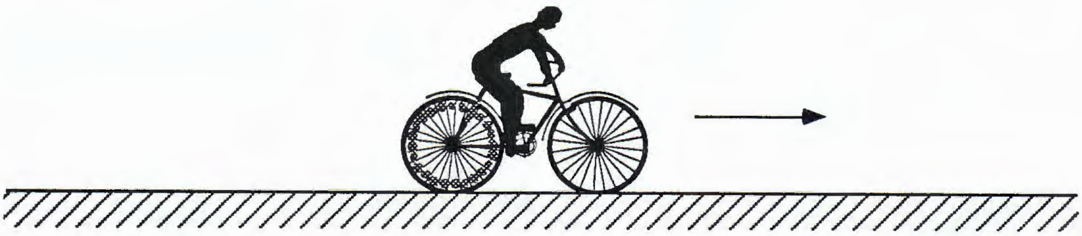


(b) Tridimensional

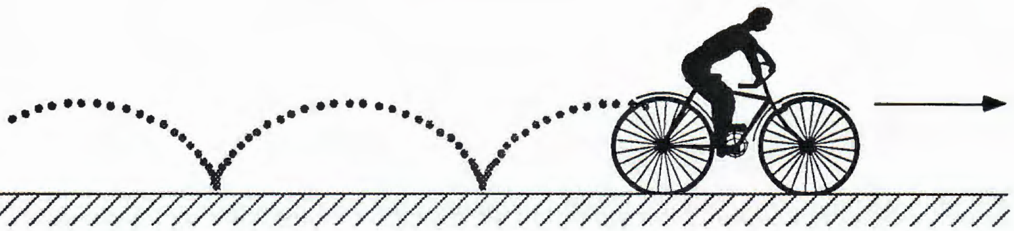
Fig. 2.4 Rectangular coordinate system

playground must be associated with a frame of reference. A question like "how far is the boy" does not make any sense unless it specifies how far from "what" ? The word "what" defines the frame of reference, without which the answer for this question will not be unique. The boy can be three feet from the swing, one and half feet from the see-saw, or five feet from the slider and so forth.

Let us suppose now an individual is riding a bicycle having a luminescent sphere at the periphery of its front wire-spoked wheels. What will be the path followed by the luminiscent sphere? Again the answer depends on the frame of reference, i.e., its path with respect to what? The path can be a circle, which is shown in Fig. 2.5a, if the frame of reference is set on the individual who is riding the bicycle, or a cycloid (a geometrical curve, described by a point on the periphery of a circle which is rolling on a straight line) as shown in Fig. 2.5b, if the frame of reference is set on an individual sitting on the curbside as an observer.



(a) Frame of reference set on the bike



(b) Frame of reference set on the curbside

Fig. 2.5 Trajectories for the luminescent sphere

Who has not experienced the following sensation when driving a car? We are going up a hill and the traffic lights become red, so we need to brake our car. On our left side we have someone driving her car in a hurry, and so impatiently she keeps rocking the car forwards and backwards. For a moment, just a fraction of a second, we have the sensation that our car is moving backward, and quickly we check out the brakes. To our relief we realize that our car is at rest. It seemed to be moving just because we momentarily had switched our frame of reference from the lamp post on the sidewalk to the other car.

In our daily physical experiences we can select countless examples similar to those described above, which will confirm the strong importance frame of reference plays for observing, measuring and analyzing the events in the physical world of our surroundings. The concepts of rest and movement are bound to frame of reference. There is no sense to state that something is in movement or at rest without having adopted a frame of reference.

$E = mc^2$ is undeniably the most popular scientific expression of our century, which is immediately associated with Albert Einstein and his theory of relativity. Behind all the complicated formulas from which the theory was derived, requiring a very accurate knowledge of advanced mathematics to understand those formulas, lies the concept of frame of reference, playing an important role and being a cornerstone in the development of the whole Einstein's theory of relativity.

I believe that these few examples are enough to make the point about the strong role frame of reference plays in mathematics and physics. But its importance does not stop here. Its definition from the The American Heritage Dictionary (1985) is "a set or system of ideas, as of philosophical or religious doctrine, in terms of which other ideas are interpreted or assigned meaning." (p. 530)

Comparing the above definition with the meaning attributed to frame of reference in mathematics and physics I can see a close similarity between both in terms of validation of ideas, meanings, and judgments attributed to the subject matter being discussed and analyzed. In addition to the examples given above about trajectory and moving objects, answers depend on the frame of reference adopted by the observer. The way a person sees the world, his moral and social judgments in the widest sense are made in the light of his beliefs, through a lens, i.e., his own frame of reference. By the time the individual becomes aware that the best solution for a problem will be found within a diversity of approaches, he will feel the necessity of using multiple frames of reference, which means to adopt different standpoints for the same situation. This kind of exercise leads to the development of skills in critical and creative thinking.

Frame of reference as a key for the development of the rational mind

A piece of knowledge becomes useless if the person does not know how to apply it outside of her own frame of reference (Paul 1987). From the moment an individual is able to leave her own frame of reference and starts to envision the situation using a piece of knowledge under different points of view, which means diversity of frames of reference, she is developing skills in critical and creative thinking. And I believe this "being outside of our own frame of reference" is the best exercise for the development of a rational mind. When the individual is able to approach a problem using diversity of frames of reference he most likely will reach the best solution using a great amount of creativity. This exercise is not an easy one since the human mind has the tendency to be inflexible (Paul 1987). One often avoids seeing the world using other frames of reference than one's own. According to Paul (1987) this tendency should be countered as early as possible. Otherwise it will become a process much more difficult to work with. Faced with this the science teacher can take full advantage of science misconceptions to start developing the skills for critical and creative thinking by the process of using diversity of frames of reference.

Frame of reference and science misconceptions

I believe frame of reference is the bridge between the inner and outer worlds of an individual. It is through frame of reference that he interacts with the world. Thus, the science teacher cannot impose new meanings or new ideas upon the students' minds without taking into account the students' systems of ideas, i.e., their frame of reference, which undoubtedly are deeply settled in their cognitive structure. I believe that the first step in the teaching-learning process is to make the students aware of the importance frame of reference plays in any kind of analyses and inference. Moreover it might help to develop the ability to approach situations under different points of view and then take account of all of them to find the best solution for it. The comparison between a prism and frame of reference seems to me adequate. While the prism decomposes a beam of white light into a brilliant spectrum of colors, an individual using multiple frames of reference can assign a wide range of meanings to the same situation. This practice gives the observer the possibility of analyzing the problem under different conditions leading to a more accurate option for the best solution and consequently a sound decision.

A good example to illustrate the importance frame of reference plays within everyday life is the role played by the trial lawyer. It does not matter if she is prosecuting or defending the defendant. Her function is to try to lead the jury to judge the situation under a frame of reference created by her. Her argument must have the effect of building a new frame of reference upon the situation in the individual's mind which will yield the verdict she planned for the defendant.

Teacher and students work together in the science classes aiming to achieve their goals which certainly must overlap. For obtaining the best results in the whole teaching-learning process teacher and students should keep the same frame of reference when discussing some topic, and learn to have flexibility to analyze the situation using various frames of reference.

Otherwise it will be very hard for them to achieve the same degree of understanding and consequently target their common goals. At the same time they will be training themselves for the development of the rational mind.

In the beginning of the process the teacher must have the expertise to see the phenomenon being discussed according to the students' background, i.e., according to their frame of reference. The teacher should take advantage of students' previous understandings to establish a linkage between the concepts students already have in their minds and the school curriculum. This idea can be soundly expressed in Ausubel's maxim that is widely cited among researchers working in the research field of science misconceptions. "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." (1968, vi)

This strategy will enable the teacher to understand how and why students are thinking in that way and find out the causes for those specific science misconceptions. Adopting this kind of approach she will be able to develop the best methodologies to promote the desirable conceptual change in the students' cognitive structure on that topic through a sound reconciliation of students' knowledge pieces, i.e, the one they brought, and the one which is being taught. Furthermore, this approach elicits the development of critical and creative thinking skills, such as making comparisons, reorganization of ideas and supporting ideas with solid and convincing arguments using multiple frames of reference.

I suppose that one of the possible causes responsible for students' failures to understand and interpret physical phenomena according to the scientific view might be associated with the lack of ability to approach the situation using multiple frames of reference. Therefore, much more important than teaching the theoretical knowledge on a specific science topic is making the students aware of their previous conceptions and challenging them to envision the problem with a diversity of approaches. This means that final inferences and conclusions will be the product of thorough analyses based upon different frames of reference. This kind of mental exercise will lead the students to have conscious control over their own learning, a process called metalearning (White, Gunstone 1989). It is extremely powerful in order to generate meaningful learning, which underlies students' ability to generalize and transfer their knowledge.

Once the student becomes aware of the important role frame of reference plays in order to obtain success in the subject matter at school, he is going to realize that the same technique must be applied to his real life. This means the student will realize he should not make any decision and/or take any risk before analyzing the situation using a diversity of approaches. The analyses and inferences should be done in the light of different frames of reference applicable for that specific situation. The issue about career choice concerning senior high school students seems to be an appropriate example to illustrate the assumption made above. During my seventeen years teaching math and physics at the secondary level in Brazil, I still remember students' anxiety and lack of criteria for making decisions about their career choice. Usually they were guided just by one criterion, such as making money, getting high social status, having a father who is a lawyer, and so on. Now I believe that this tense situation could be minimized if they were taught to approach situations using multiple frames of reference.

I believe that even though the content of a specific science topic may not be learned in depth and did not bring the student from the novice to the expert stage in that subject matter, she can surely develop the expertise to broaden her horizons throughout her life, and the teacher's work can be taken as well done, because he prepared the individual for life.

Making students aware of the importance of frame of reference will not solve all the problems posed by misconceptions in the science curriculum. It is very important to be aware that within the teaching-learning process several other factors and parameters are involved, e.g., the compatibility between the student's style of learning and the teacher's style of teaching, motivation, and the previous students' environment, just to name some of them.

It is not my intent at this point to discuss the issue of what should be the set of skills an individual needs to become a critical thinker. Instead my attempt is to focus on the importance of the three-fold linkage of frame of reference (FR), the process of critical and creative thinking (CCT) and the science misconceptions (SM) phenomenon.

I can see these three elements as the vertices of an equilateral triangle as shown in Fig. 2.6. No matter what the position of the triangle, the interrelation within the three elements is the same. Science misconceptions is a phenomenon that should be approached using diversity of frame of reference, which is a strong element to improve the skills for critical and creative thinking. Conversely critical and creative thinking is a process in which frame of reference plays an important role in the sense it gives the individual freedom of thought and flexibility of mind ensuring science misconceptions will be surmounted in a process of complete awareness.

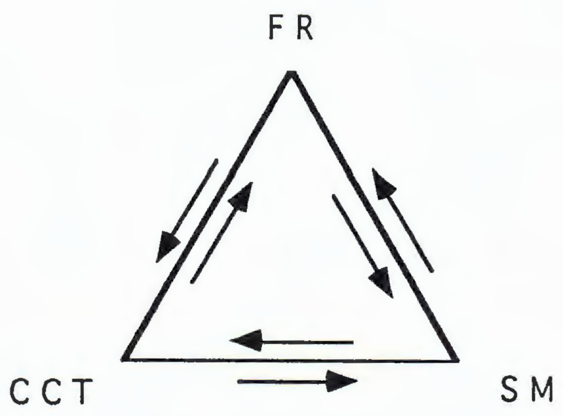


Fig. 2.6 The three-fold linkage: CCT, FR and SM

It is my view that frame of reference encompasses most of the critical thinking skills itself, enabling the individual to approach a situation with a diversity of frameworks. This is possible because the individual leaves her solipsistic posture allowing the actualization of her latent traits to become a good thinker in a natural, but conscious process (Paul 1987).

What a critical thinker is could be summed up in the following way: an individual who has the sensibility of observing the world in the same way a piece of glass in its prismatic shape does with a beam of white light passing into it, breaking up that beam of white light in a rainbow-like band of colors namely red, orange, yellow, green, blue, indigo, and violet. The critical thinker has the ability to perform in a very similar way when he uses diversity of frame of reference. He breaks up the situation into its very small parts and from these reconstructs new hypotheses and inferences, coming up with the best solution.

In the field of science misconceptions both teacher and students have different frameworks for the specific topic being studied. They set their frame of reference in a very individual way which I believe is based on the scripts (Gardner 1991) they have constructed throughout their lives in order to give meaning to all the events that have occurred in their surroundings. Obviously the teacher carries with her the scholastic background which supposedly makes her an expert who thinks scientifically on the subject matter while the students are the novices who bring their naive beliefs to the science classes.

I believe this state of affairs makes the teaching-learning process difficult by generating constraints that certainly will jeopardize the process. It is necessary that teacher and students be engaged in the process as co-workers who are aiming at the same objectives.

At the moment both teacher and students become aware of the need to focus that content upon the same context, they will start using the same language, which means to approach the content embedded in that situation using the same frame of reference. This atmosphere will generate a reconciliation between the piece of knowledge students bring with them, also called earlier understandings (Gardner 1991), and the new knowledge being taught in that science class.

Science Misconceptions: a Major Concern?

I believe that at this point an issue remains regarding to what extent science misconceptions should be considered a major concern and their implications within the teaching-learning process of science. It is very difficult to come up with rigid and closed conclusions when the subject in the research field is the human being. In this case, it would be very difficult to do a longitudinal study, i.e., to follow a group of students who presented science misconceptions in their science classes through their personal and professional life.

Outcomes from studies focusing on students' frameworks about scientific topics, namely physics, chemistry and biology, have shown that misconceptions are present, that they are deeply rooted in students' cognitive structure, and as a consequence they interfere with the new and scientific concepts being taught at school, and all the other hypotheses described in the beginning of this chapter on page . What studies have not provided is an answer to the issue posed in the first paragraph of this section. To what extent should science misconceptions be considered a major concern in the teaching-learning process in science?

It has not been acknowledged or at least there is nothing in the literature about damages caused to the student's personal and/or professional life as a consequence of carrying science misconceptions from the school to later life (unless he is going to pursue a career as a science teacher !).

Despite the fact that students who leave school keep their previous conceptions about natural phenomena, which sometimes are in disagreement with the scientific view, things have been working well. After all the wide range of scientific discoveries, the breakthroughs in the scientific and technological areas are the product of human minds who passed through this scholastic process. Let us go back just a few decades and compare the population who entered school and the population who graduated from college. Even in developed countries, they were a minority and privileged population (Gardner 1991), so this is the reason why things were apparently going well. In countries in development like mine, Brazil, it is very fortunate if the population who enter school leave it at least being able to read, write and have some rudiments of basic arithmetic.

The realization of the incompatibility between the knowledge students bring with them to the science classes and the formal knowledge being taught at school was triggered by factors like the significant growth of school population and changes in the curriculum toward a more significant and efficient content stressing the role of science and mathematics in order to attend to the exponential development of technology. This state of affairs has gained the attention of many groups involved with science education who target their efforts in the study of science misconceptions, many times considered the kernel of students' failures in science. This sort of approach leads the community to envision the phenomenon of science misconceptions as a major concern within the teaching-learning process. This to me means finding the cure for the pain, not for the disease, which I identify as students' lack of thinking about their own thinking in a very conscious and controlled way (Kuhn 1993).

Faced with this problem, my view is that the major concern should not be the eradication of science misconceptions, although it will most likely happen at the end of the process. The main goal should be centered on the development of skills in higher order thinking using the students' own science misconceptions as a springboard in the whole process.

It is undeniable that society needs critical thinkers, that is, individuals who are always prompt to surmount challenges through the amalgam of their rational and emotional senses; individuals who are able to deal with many situations at the same time coming up with the best solution for each of them; individuals who are self-confident in their capacity for solving problems and therefore always prompt to take risks, because above all they are aware of their weaknesses and strengths.

Conclusions

Science misconceptions, frame of reference, and critical and creative thinking were the three major themes discussed in this chapter. They are interconnected, complementing one another. First, there is a consensus within the community in the field of education on the necessity of developing the skills for a rational mind: students must leave school possessing the basic skills in critical and creative thinking. Second, it is well known that students' academic performance in science has been very poor, not just in terms of grade achievement but in terms of meaningful learning. That is, students are often unable to transfer the knowledge acquired at school to everyday life. They come to the science classes holding some conceptual frameworks about physical phenomena which conflict with the scientific view, science misconceptions. Most of the time even straight A students leave school holding the same understandings and beliefs they entered with.

Finally an important skill for a critical and creative mind is having the flexibility to move from one frame of reference to another. This means to possess the capacity to move away from an egoistic point of view and to become aware of the gamut of ways of thinking about an issue. This is an important ability, since the issues faced in everyday life are multilogical issues, that is they are settled within a diversity of frame of reference. This opposes the school pattern where most of the questions are settled within just one frame of reference. That is they are monological issues (Paul 1987). This hampers the student' s opportunity to develop the important skills in critical and creative thinking which will enable him to deal with reality in a satisfactory manner.

The goal is to teach academic subjects in such a way as to overcome science misconceptions in a meaningful way while taking advantage of them to develop the skills for grooming individuals with rational minds. This process will enable students to transfer the knowledge they acquired during the academic years to everyday life instead of keeping them as inert knowledge, i.e., knowledge the individual has and does not know how to use (Bransford 1987).

Physics, chemistry and biology have been the fields of science chosen in the studies about science misconceptions. As shown in Table 2.1, physics has been widely explored, and within its domain, mechanics holds the largest number of studies. In the next chapter I will present a brief literature review of misconceptions in mechanics, mainly about force and motion. The main reasons for this specific choice are the following: a) The huge number of studies done in mechanics leads to replications, making it possible to compare the findings and then the final conclusions.
b) Mechanics encompasses the most common everyday life experiences, allowing for comparison between individuals' spontaneous ideas and scientific theories and making possible the development of skills in critical and creative thinking through the approach of multiplicity of frames of reference.

CHAPTER III

MISCONCEPTIONS IN MECHANICS - A LITERATURE REVIEW

Introduction

It is not my intent here to give a definition of mechanics. It is adequate for the purpose of this thesis to outline its role within the field of physics. Informally, mechanics is the branch of physics concerned with motion and its causes.

Another point I consider relevant for this chapter is that all findings from the surveys done in the field of mechanics were based on Newtonian mechanics, i.e., classical mechanics. From now on the word "mechanics" will be used to mean classical mechanics.

As usual, for didactic purposes, classical mechanics is divided into kinematics, i.e., the descriptive study of motion taking into account the relationships among the parameters of speed, position and time, and dynamics, concerned with the causes of motions.

Usually mechanics is studied at the outset of a formal course in physics for its essential role as the foundation for the learning of other subjects in physics (Halloun and Hestenes 1985). This might be one of the reasons why it has been extensively explored in the research field of science misconceptions (Linn, Clement, Pulos and Sullivan 1989), holding the plurality of studies done among areas in physics as shown in Fig. 3.1 (Duit 1993).

In our daily experiences we are exposed to countless phenomena which can be scientifically explained by the laws and theory of mechanics. Indeed the human being has her first experiences with such phenomena very early in her life, from the moment she is able to use her senses and

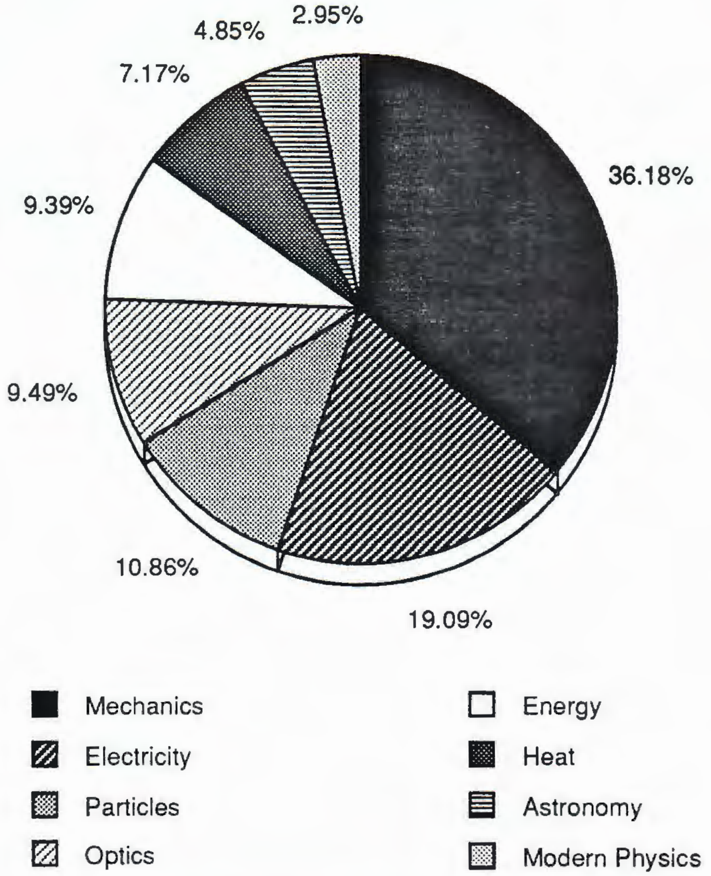


Fig. 3.1 Studies about students' misconceptions in mechanics compared with other areas in physics up to 1993 (Duit 1993).

cognitive functions and starts to interact with the world after birth. The fall of a spoon, the movement of the little bears hung on her crib, that red ball bouncing up and down, the steady movement of a swing, the displacement she needs in order to reach that yellow rubber duckling, that stone whirling at the end of a string which suddenly was broken making the stone end up at the neighbor's window, the push she needs to give to that little train in order to put it in motion, and so forth. These are just a few examples of the huge number of experiences in the domain of mechanics that all of us are exposed to during our lifetimes.

Later on, by the time she reaches school age, these experiences will be part of her cognitive structure, i.e., schemes stored in her long-term memory. They might or might not be in agreement with the scientific models, and if the latter is the case such an informal piece of knowledge, i.e., a spontaneous concept (Vygotsky 1986) will be labeled among others as a science misconception.

Within the wide range of studies that have been conducted in mechanics the surveys have concentrated upon the concepts of force and motion (Newton's laws), free fall, and energy. Studies in this area have shown a remarkable similarity among the findings presented on topics redone several times by different investigators on different populations such as different levels of instruction in physics from different socio-economic classes, etc.

There is evidence from the findings suggesting a well defined kind of reasoning pattern coherently structured in the students' minds resembling in some aspects the pre-classical mechanics developed in the middle ages, as well as partially the Aristotelian physics (McCloskey 1983a, 1983b; McCloskey, Caramazza, and Green 1980; Lie, Sjøberg, Ekeland and Enge 1985; McDermott 1984; Halloun and Hestenes 1985; Thijs 1992). However, this is a controversial issue which have raised some different opinions among researchers. Saltiel and Viennot state:

> ... a parallel between spontaneous reasoning and such and such a stage of historical theory may work partly, but it works only partly. So obviously it does not dispense us of investigating further our students' conceptions. It would be an oversimplified attitude to ascribe a whole historical paradigm, say Aristotelian or pre-galilean, to a student for the only reason he has made such and such mistake, or even a group of mistakes. (1985, p. 207)

I would like to stress here the same point I made in Chapter II. There is a lack of studies focusing on students' misconceptions as a rich source for the development of instructional and pedagogical strategies aiming not just at the overcoming of those misconceptions, but, more important than that, at taking advantage of this state of affairs to teach the students how to transform their spontaneous reasoning into reflective reasoning, which means the development of higher order thinking.

Impetus Theory

Impetus theory was developed historically during the pre-Newtonian mechanics period to explain the causes for a moving object. The huge number of studies about students' prior knowledge about force and motion have shown a similarity between this theory and students' naive theories.

Before presenting some of the most common findings in the research field of misconceptions in mechanics involving mainly the concepts of force and motion, I believe it is useful to discuss impetus theory. What is it and what is its role within the study of this research field?

Historical background

This theory was largely developed from the fourteenth to sixteenth centuries (McCloskey 1983a, 1983b). Saltiel and Viennot stated:

> These theories, which go back as far as the VIth century (J.Philopon) and were developed mainly around the XIVth century, were still at the background of Galileo's thought." (1985, p. 200)

The impetus theory was the product of criticisms and subsequent revisions to Aristotelian physics. While Aristotle's ideas about motion were that the medium was the cause for the continuity of the movement of an object, (i.e., the cause was external to the moving object), the revised ideas were that what kept the object moving was an internal force --impetus, imparted by the active agent which first propelled the object. Jean Buridan, a French philosopher in the fourteenth century called this force "impetus" and he was responsible for the final elaboration of the medieval impetus theory. It served as the foundation for explaining the motion of objects in a straight line as well as circular movements, proposed by some theories in the fourteenth century to explain the motion of celestial bodies around the earth. McCloskey, Caramazza and Green quoted Clagett (1959) on Buridan's theory:

> "The motor [i.e., the agent that sets an object in motion] in moving a moving body impresses in it a certain impetus or a certain motive force of the moving body, [which impetus acts] in the direction toward which the mover was moving the body, either up or down, or laterally, or circularly." (1985, p. 1140)

According to Newton's first law of motion no force is required either to keep a body in movement at a constant speed in a straight line or to keep a body at rest according to the frame of reference adopted. For example, a book on a table in a train moving at uniform velocity can be considered at rest if the frame of reference chosen is the train or in motion if a place on the earth is chosen as a frame of reference. Therefore, if there is no variation in the speed and direction of the object, a state of rest and a state of uniform velocity are equivalent. This assumption is false within the framework of the medieval impetus theory. That is, the state of rest and the state of movement are distinct because impetus is associated with motion, but not with an object at rest.

In short the two fundamental assumptions about motion according to the medieval impetus theory are: 1) when a body is put in motion it acquires an internal force called impetus which sustains the movement; 2) the body will start slowing down and will stop because the impetus it possesses is going to dissipate (McCloskey 1983b).

The parallel between the medieval impetus theory and students' framework about motion

When an object in motion stops, one is more likely to hear a student say "it stopped" instead of "it was stopped." The student thinks the cause of its stopping is going to be: "its force finished" or "it lost its force." Its slowing down until it stops will be attributed to a steady loss of an internal force transmitted to it by the external agent in the initial pushing. This is a very common belief among students. McCloskey (1983b) called these beliefs a naive impetus theory. This belief and the medieval impetus theory share a common point, that for every motion there is a cause, the impetus, an internal attribute of the object in motion impressed on it by an external agent.

Selected Findings on Students' Framework about some Basic Concepts in Mechanics

As I have been stating mechanics is the branch of physics that has been given the largest number of studies related to science misconceptions. During the last two decades studies involving the notions of force and motion have shown a common set of beliefs regardless of race, social-economic status, and level of knowledge in physics. The results support the investigators' general conclusions that there is a gap between students' naive theories and scientific theories regarding the way of explaining everyday physical phenomena. Sometimes in our everyday experiences we are deceived by our senses. This led us to frame that specific situation in such a way fitting our reality, but most of the times it opposes the scientific theories.

Force versus motion

According to Clement (1982) the question proposed below was designed with the objective of isolating the source of students' prior knowledge of the principle that motion implies force. The question was part of a diagnostic test taken by a group of engineering students in the beginning of their first semester in a course on introductory mechanics. Their background in physics was for most of them only high school physics. The proposed question was:

> A coin is tossed from point **A** straight up into the air and caught at point **E**. On the dot to the left of the drawing draw one or more arrows showing the direction of each force acting on the coin when it is at point **B**. (Draw long arrows for larger forces) (1983, p. 327)

The findings showed that 88% of the subjects gave the wrong answer shown in Fig. 3.2, supporting the investigator's predicted hypothesis that the principle that motion implies force, i.e., the medieval impetus theory would be present in students' reasoning.

Another point I consider relevant to present is related to the persistence of this misconception even after the subjects had concluded the course. A post-course test was designed and applied to a group of subjects (not the same group who took the diagnostic test). The percentage of incorrect answers was 75% compared to 88% before having formal instruction on that topic. This fact confirms the assumption that misconceptions are deeply incorporated in students' cognitive structure and are hard to overcome.

This sort of problem was repeated by other investigators with small changes, such as throwing a ball instead of a coin straight up (Thijs 1992; Watts and Zylberstejn 1981; Halloun and Hestenes 1985; Lie, Sjøberg, Ekeland and Enge 1985). The relevance lies in the similarity of the final

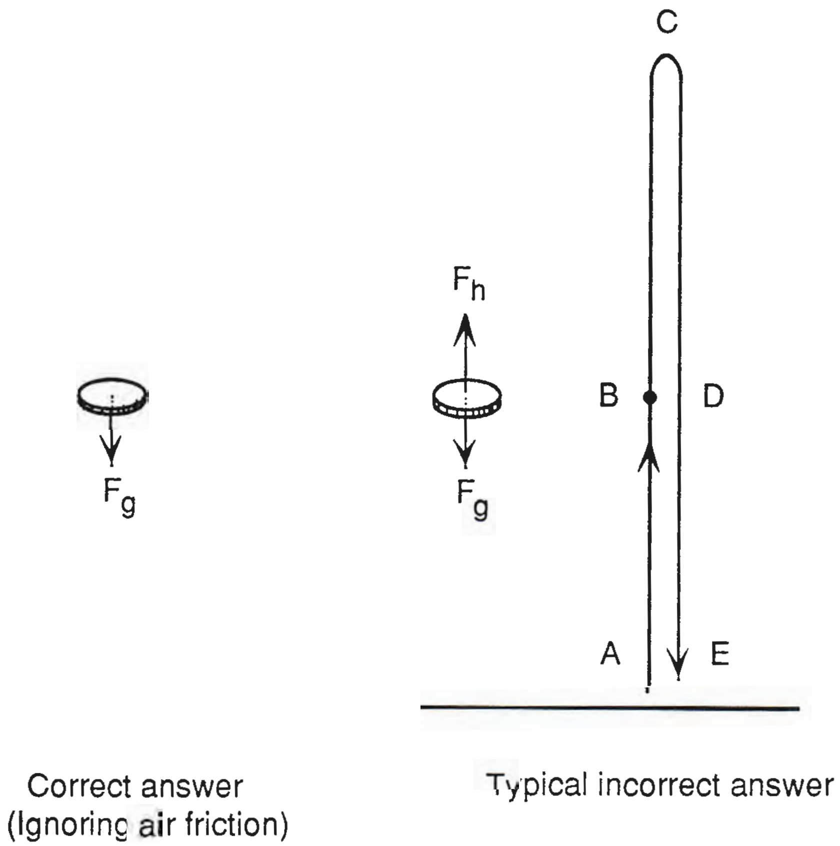


Fig. 3.2 Answers to the coin problem (Clement 1983)

findings: the medieval impetus theory was dominant within students' answers.

Fig. 3.3 shows an incorrect answer given by students who were asked to solve the problem below (Clement 1982). They were taking an introductory course in mechanics and worked with a pendulum in the laboratory.

> (1) A pendulum is swinging from left to right as shown below. Draw arrows showing the direction of each force acting on the pendulum bob at point A. Do not show the total net force and do not include frictional forces. Label each arrow with a name that says what kind of force it is.
>
> (2) In a similar way, draw and label arrows showing the direction of each force acting on the pendulum bob when it reaches point B. (Clement 1983, p.326)

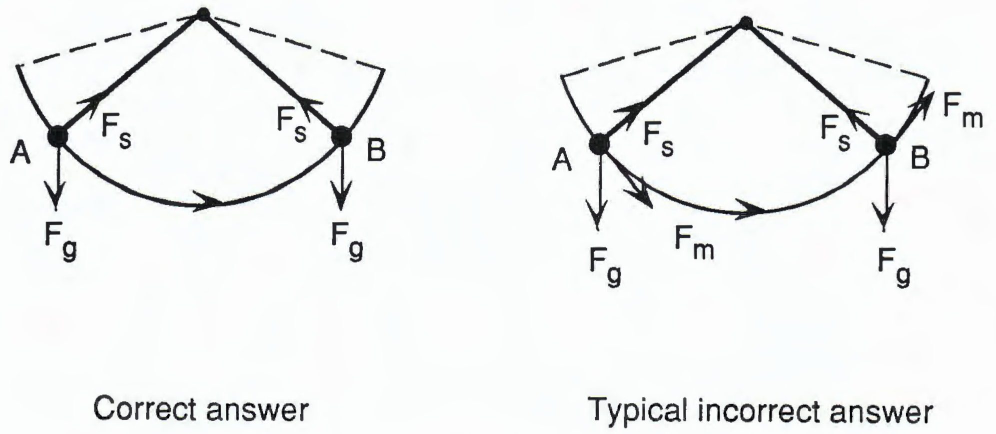


Fig. 3.3 Answers to the pendulum problem (Clement 1982)

Again a force, F_m, to justify the upward movement of the pendulum is present in many students' answers. It seems that many students have the misconception that motion implies force, i.e., that a continuing force in the direction of a moving object is necessary to sustain the movement.

Curvilinear motion

Studies on curvilinear motion have shown that students also believe in a circular impetus (McCloskey, Caramazza, and Green 1980), which means that an object in a circular movement when released is going to follow a curved path. This contradicts Newton's first law which states that a straight line will be the path of an object in motion if no forces are exerted on it. The following two problems were proposed to Norwegian students with different levels of instruction in physics, including some of teacher training colleges (Lie, Sjøberg, Ekeland, and Enge 1985). McCloskey and his associates (McCloskey, Caramazza, and Green 1980) designed and applied a similar sort of problems with slight variations. Subjects were undergraduate students at different levels of instruction in physics. The schematic representation for both problems is shown in Fig. 3.4. The questions proposed were:

> 1) A stone is tied to the end of a rope moving in a circle until the rope breaks. At the point A shown in the diagram, the rope breaks. Draw the path followed by the ball after the rope breaks (ignore air resistance);
> 2) A ball is moving along a C-shaped tube placed on a table, as shown in the diagram. The ball is shot into the tube at point A and exits at point B, as shown in the diagram. Draw the path followed by the ball after it leaves the tube.

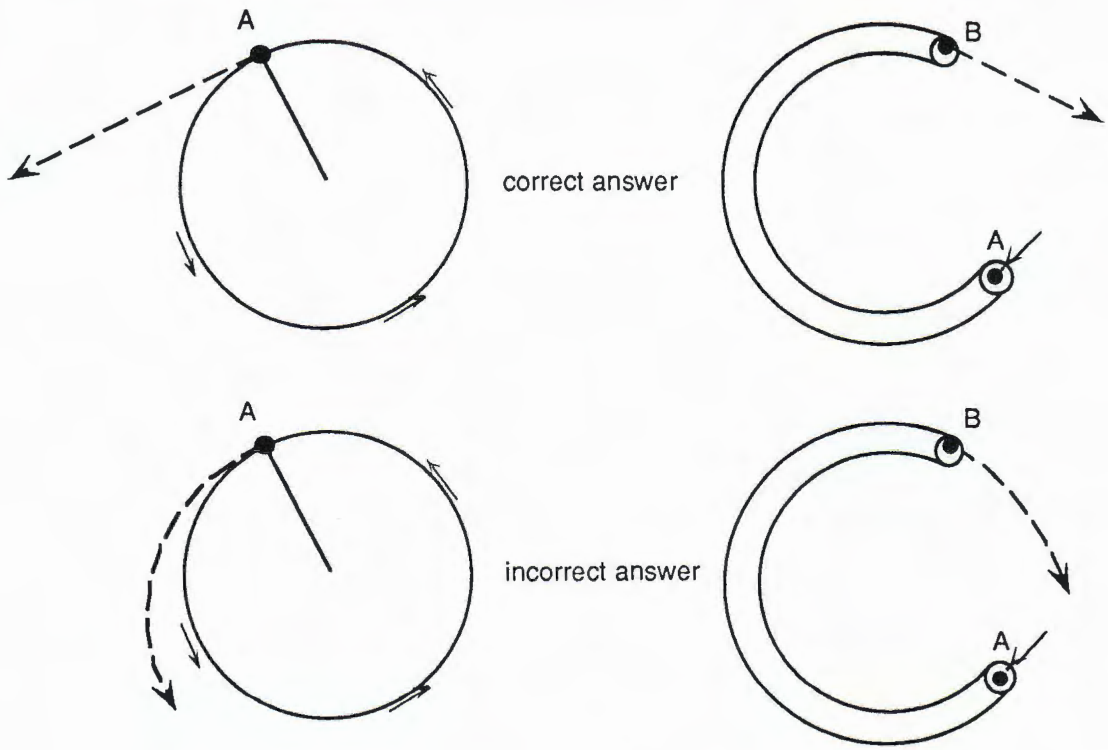


Fig. 3.4 Diagram for the string problem (a) and the C-shaped tube (b)

The final findings from McCloskey and his associates for the string problem were that 30% of the subjects presented a wrong answer. They believed that after the string broke the ball would continue its circular path. For the C-shaped tube problem one-third of the subjects concluded that the ball would have a curved path after leaving the C-shaped tube.

The study with the Norwegian students showed an average of 40% of the students thinking that the path described by the stone after the string break would be circular, and an average of 30% of the subjects gave a circular path as an answer for the C-shaped tube. Once again students' beliefs about certain physical phenomena resemble the medieval impetus theory regardless of factors like race, instruction, etc. Another relevant aspect concerns the similarity between the results obtained in both studies, i.e., the one with Norwegian students and the one conducted by McCloskey and his associates. This fact confirms that there is a general pattern among students' system of beliefs about natural phenomena.

Predicted trajectories of moving objects

Another common misconception among students is about the path described by a body released from a moving object. The following problem was used by McCloskey (1983b) and his associates in one of their studies on misconceptions about motion:

> In the diagram [Fig. 3.5], an airplane is flying along at a constant speed. The plane is also flying at a constant altitude, so that its flight path is parallel to the ground. The arrow shows the direction in which the plane is flying. When the plane is in the position shown in the diagram a large metal ball is dropped from the plane. The plane continues flying at the same speed in the same direction and at the same altitude. Draw a path the ball will follow from the time it is dropped until it hits the ground. Ignore wind or air resistance. Also, as well as you can, draw the position of the plane at the moment the ball hits the ground. (McCloskey, 1983b, p.302)

Before going further and presenting the investigators' outcomes, I would like to note that during several years teaching mechanics in an introductory course of physics for senior high school students in Brazil during the 1970s and 1980s, I used to include this problem systematically

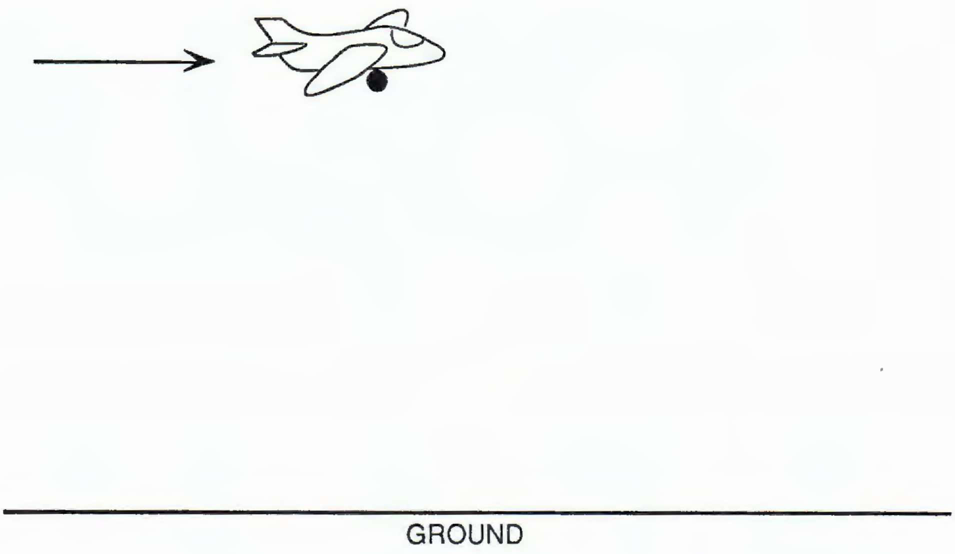


Fig. 3.5 Schematic representation for the airplane problem (McCloskey 1983b, p.302)

in a pre-test of students' previous knowledge of some basic concepts in mechanics. Each year the findings were almost the same, an average of 70% incorrect answers such as the ones shown in Fig. 3.6b, 3.6c and 3.6d.

This same problem was presented informally to my colleagues taking the course CCT 685 (Educational Evaluation) taught by Dr. Murray during the Spring of 1992. Among the total of 13 answers, only 2 were correct, which means an average of 85% incorrect answers.

The correct answer to this problem is represented in Fig. 3.6a. The path described for the ball after it is released is a parabolic arc. Besides it is relevant to observe that by the time the ball reaches the ground the airplane will be in the same horizontal as the ball.

McCloskey and his associates presented this problem to 48 subjects and the responses obtained were: a) 40% of the subjects drew a parabolic arc very similar to the one shown in Fig. 3.6a. However, one fourth of them thought that the airplane would be horizontally ahead from the ball at the moment it reached the ground, which is a wrong conclusion. The ball and

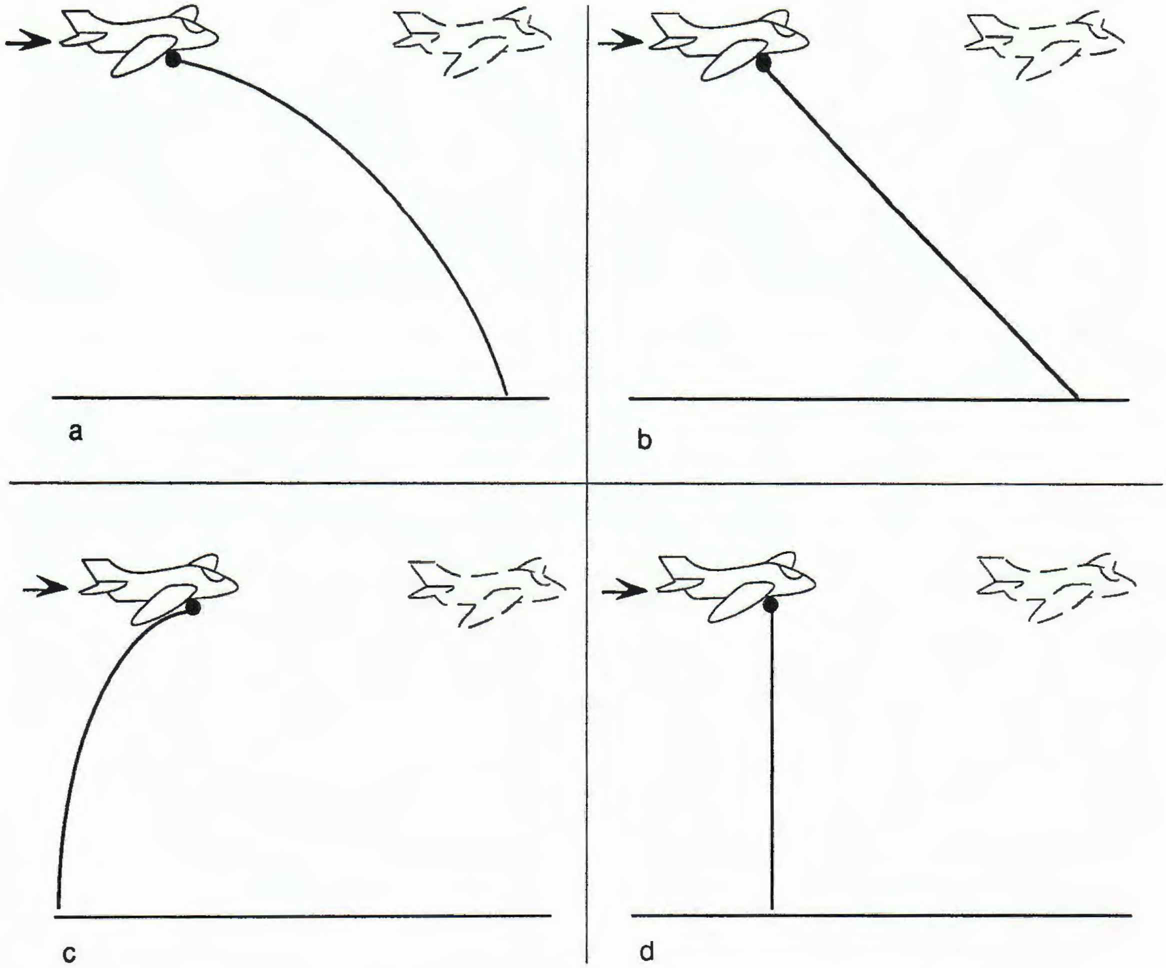


Fig. 3.6 The airplane problem - correct answer (a) and some common incorrect answers (b,c,d). (McCloskey 1983b, p. 303)

the airplane are going to have the same horizontal position by the time the ball hits the ground. b) 13% of the subjects drew the diagram shown in Fig. 3.6b, a straight diagonal line. c) 11% of the subjects drew the diagram shown in Fig. 3.6c. They believed that the ball would move backwards after being released. d) The most common incorrect answer is represented in Fig. 3.6d. 36% of the subjects believed that the path described by the ball after its release should be a vertical straight line. McCloskey and his associates concluded that people lack conceptual understandings about projectile motion of objects having horizontal and vertical motion simultaneously.

It seems to me that one important point ignored by the subjects in the study described above as well by my students in Brazil and my colleagues at CCT was that the horizontal velocity of the ball is equal (in magnitude and direction) to that of the plane. At the moment the ball is released it acquires a constant increasing vertical velocity due to gravity. Its final velocity is the composition of both velocities, horizontal and vertical, which will make its trajectory a parabolic arc. Furthermore, because both the ball and the plane have the same horizontal velocity the plane will follow the ball exactly above it until the moment it hits the ground. This situation is similar to the situation of a person getting off from a vehicle in movement. To avoid being thrown to the ground he should run at the moment he touches the ground, which means keeping a velocity (equal to that of the vehicle) he had at the moment he jumped out of the vehicle. Another point related to the airplane experiment concerns the frame of reference adopted to solve the problem. A frame of reference set in the plane will yield an answer shown in Fig. 3.6d, while the answer from Fig. 3.6a is associated to a frame of reference set on the ground. In the problem proposed by McCloskey and his associates, no frame of reference was mentioned which might have caused a dubious interpretation of the situation. If the subject set the frame of reference in the plane the answer shown in Fig.3.6d is the correct one instead the answer shown in Fig. 3.6a. Viennot stated:

> Changes of frames of reference give rise to particularly strong conflicts between intuition and taught formalism. They merit an important place in the teaching of mechanics, not only because they are difficult (which could deter) but also because they ruthlessly reveal mistakes which are latent in problems with only one frame of reference. (1979, p.216)

The matter regarding frame of reference seems to me an important and central point related to the issue being discussed, misconceptions in mechanics, as well as for the development of skills in critical and creative thinking. The physics teacher must take the advantage and opportunity when working with this kind of problem during science classes to engage students in a peer group discussion about the important role played by frame of reference in everyday life as well as in physics. I believe that the discussion will be enhanced and productive if the teacher leads the students to think about the analogy that exists between the role of frame of reference in the physics context and in the everyday life situations, asking the students to thing of situations they have experienced in their everyday life that should be judged using multiple frames of reference.

Forces acting on static objects

Minstrell (1982) conducted a study among his high school students of their conceptions of forces acting on an object at rest before and after they had formal instruction about forces. The study took place in the environment of a physics classroom. The main goal in this investigation was to develop and apply critical and creative thinking as a technique to promote the desirable conceptual change in students' reasoning on that phenomenon through a process of self-awareness. Below are a list of the instructional techniques designed and executed by Minstrell:

> a) an engaging, free thinking, free speaking social context in which students are encouraged to articulate their beliefs, b) a juxtaposition of a variety of first-hand experiences with static objects, and c) encouragement to search for the simplest, consistent, rational argument that will explain the similarity of effects in an apparent diversity of experiences. (1982, p.10)

The first part of this study consisted in asking the students to draw the forces acting on a book at rest on a table. Among 25 students surveyed 14 (56%) did not include the upward force acting on the book, drawing just the arrow representing the downward force of gravity, as shown in Fig. 3.7b.

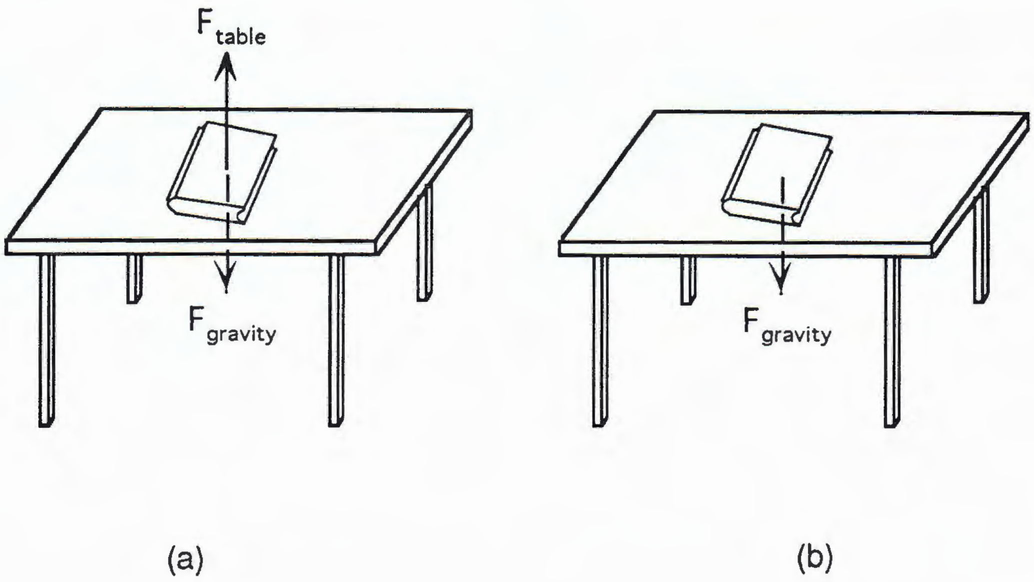


Fig. 3.7 Forces acting on a book on a table - (a) physicist's view (b) students' misconception

After that, Minstrell performed a sequence of demonstrations aiming to show in a concrete way the necessity of an upward force to sustain the book. The sequence of situations were: a) the book was placed on the outstretched hand of one student, and more books were added to the student's hand; b) the book was placed hanging from a spring; c) the book was placed on the table again and a beam of light reflecting at a low angle off the table top to the wall enabled students to see the depression on the table when the teacher stood on and off the table. In each of the cases described above, students were encouraged to share their ideas with the teacher and colleagues. They were also asked to support their arguments.

The findings summarized in Table 3.1 lead to the conclusion that the techniques and strategies designed by Minstrell had a significant influence upon students' initial understandings, promoting a satisfactory conceptual change not by the authority of the concepts imposed by the instructor but on the contrary through a thorough evidence of actual facts evolved basically from the use of peer group discussion, i.e., dialogical thinking (Paul 1987).

Table 3.1 Conceptual change in students' framework in thinking about the forces acting on a static object

Change toward force exerted by the table			
	Number of students		
Sequence of events	Believing down-ward force only	Undecided	Believing upward force by support as well
Discussion of what force is, and introduction of use of a vector to represent it			
Book on table (poll taken)	14	1	12
Book on hand (poll taken)	13	1	13
More books added to hand			
Book on hand (poll taken)	6	1	20
Book on spring (poll taken)	1	1	25
Book on table (poll taken)	9	3	15
Reflect light beam off table with instructor standing on, then off the table, and hang light weight ruler on spring			
Book on table (poll taken)	1	1	25

Source: Minstrell 1982, p. 12

It seems to me that this is the adequate environment that gives the students an opportunity to analyze the situation from different perspectives, other than the one proposed by the teacher's authority and textbook. Students can frame the same situation differently, which will enable them to define the problem using multiple frames of reference. This kind of exercise forces the student to confront his system of beliefs with the ones held by his peers and vice-versa.

<u>The relation between force and speed of motion</u>

Fig. 3.8 (Viennot 1979) shows a set of juggler's balls in a given instant when they have the same height above the ground, but different speeds and directions of motion, as indicated in the diagram. Air resistance is ignored. The question was: Are the forces acting on all the balls (or masses) identical at that instant? (The method used for the survey was a pencil-and-paper test taking about 30 minutes)

The forces in the given instant depend only on the positions of the balls and not on their motion, therefore the forces for all the balls in that given instant are equal. For many students the answer does not look so obvious as shown in Table 3.2 below. According to Viennot (1979), the findings demonstrated that almost half of the students surveyed have the misconception that different velocities imply different forces. Furthermore, many of the students seem to be reasoning using an intuitive law represented by a linear relation between force and velocity, F = kv, where k is any constant, and supported by comments like: "The motions are not the same, so the forces are different; "The velocities are different, so the forces are different too." It seems that the direct association between force and velocity is confirmed by the everyday experience of riding a bicycle for example. The faster you want to ride it, the more "force" you need to apply on it. This association "force and velocity" seems to be an obstacle to understand the relation between acceleration and force.

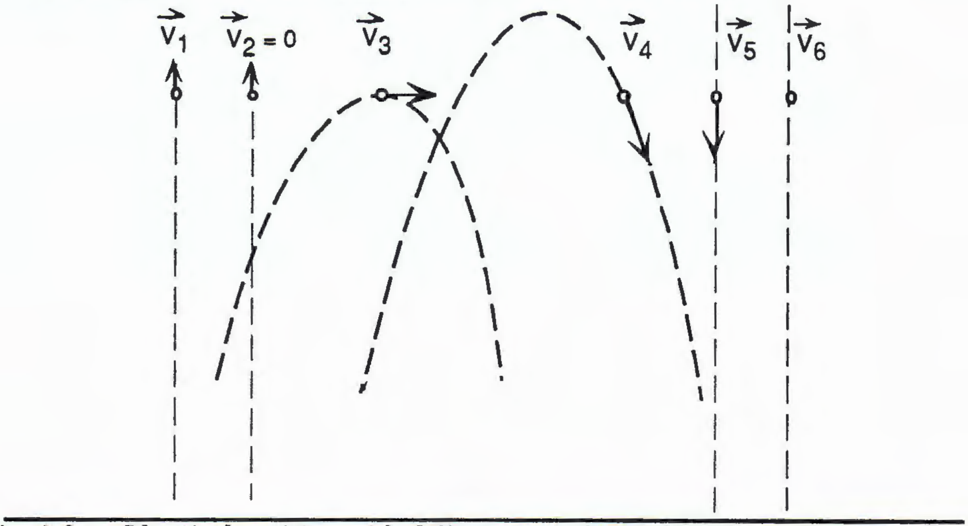


Fig. 3.8 Identical position with different speed and directions of motion (Viennot 1979)

Table 3.2 Responses to the question about the forces acting on the balls in Figure 3.8

NUMBER OF STUDENTS RESPONDING	STUDENTS' YEAR OF STUDY	THE FORCES ARE... equal	not equal	no reply
29	Last year of secondary school	39%	55%	6%
36	First year university	58%	42%	0%
226	First year university (Belgian)	44%	54%	2%

Source: Viennot 1979, p. 207

Conclusions

The studies described above are just a small sample of an extensive amount of work dealing with students' misconceptions in mechanics mainly about force and motion. However, they depict the essential features of students' understandings about force and motion constructed on a basis of everyday experiences. In the following I will summarize the major conclusions from these studies.

Everyday versus scientific language

Many concepts in mechanics are defined by words used in everyday language, such as "force," "speed," "velocity," "energy," "power," "work," "acceleration," etc. Most of the time they do not share the same meaning within these two contexts and this has been considered one of the sources of students' misconceptions (Duit 1987; Driver 1985; Champagne, Gunstone, and Klopfer 1985). In mechanics, to accelerate means to speed up, to slow down and to change direction. Its everyday meaning most of the time is associated to the concept of speeding up only. Champagne, Gunstone, and Klopfer (1985) conclude:

> For example, students use the term speed, velocity and acceleration interchangeably; the typical student does not perceive any difference between two propositions such as these: (a) The speed of an object is proportional to the [net] force on the object; (b) The acceleration of an object is proportional to the [net] force on the object. (p. 67)

Similarities among different populations surveyed

Since the mid-1970s some specific questions, such as the ones described in this chapter, have been replicated by different investigators and the findings have been confirmed even when parameters like race, background, ages, and socio-economic status are variable.

Propositions like "motion implies force," "heavier objects fall faster than lighter ones," and "there is no force acting on a body if it is at rest," are commonplace within students' explanations. According to Driver (1985) this is something to be expected since we all live in an environment where motion and other natural phenomena present the same feature, for example, at the moment a child starts interacting with the external world she will start experiencing that to put a body in movement it is necessary to give it a push and that it is going to stop few moments after that initial push. No wonder students' understandings about world events like motion, for example, resemble ideas held by scientists centuries ago.

Pre-Newtonian versus Newtonian mechanics

The findings from a large number of studies about mechanics have shown that students' understandings about motion are much closer to Aristotelian and medieval physics than to Newtonian mechanics (Clement 1983; McCloskey 1983a, 1983b). One possible reason for this outcome could be that Newtonian mechanics is a scientific theory which has been developed by taking in account ideal conditions, i.e., no friction, no air resistence, and so on. The everyday world does have these parameters leading the individual to construct meanings based on what he concretely observes. For example, the general tendency of a moving object is to slow down before stopping because its force is getting used up. This sort of thought resembles the medieval impetus theory (McCloskey 1983b) where the impetus is the amount of "something" inside the body that explains its motion.

Students' misconceptions resistent to change

There is common agreement among investigators (Champagne, Gunstone, and Klopfer 1985; Duit 1993; McDermott 1990; Saltiel and Viennot 1985) that prior knowledge students bring to science classes is deeply rooted in their cognitive structure and works as a barrier to the acquisition and understanding of that subject according to the scientific interpretation of it. It is not an isolated fact that students hold their beliefs even after having formal instruction on that topic. Driver (1985) states: "The frequency with which university physics students use alternative ideas [science misconceptions] about force and motion indicates the persistence of these ideas." (p. 180)

McCloskey (1983a) reported that in one of his studies about motion he tested high school students' knowledge about motion before and after a physics course. The findings showed that the impetus notion was present in about 80% of the students after the course versus 93% before having formal instruction.

Implications for Educational Practice

Students' misconceptions in mechanics have played an important role within educational practice. It has been the foundation for the development of new epistemological and psychological views in education. There is now an attempt among the community directly or indirectly involved with education, such as psychologists, philosophers, curriculum developers, instructors of all levels, educators, etc., to join efforts for the design of an educational practice centered much more on individuals' potentialities and the demands of society.

Current situation

Teachers complain that it is difficult to teach mechanics mainly because of students' lack of interest, background, and mathematical skills. Students complain that it is difficult to learn mechanics because it is a very complicated and difficult subject, and they do not know where they are going to apply the subject matter, i.e., what is the purpose of studying mechanics.

Today this state of affairs has its positive aspect, functioning as a driving force for the new philosophy and vision of practice in education.

Current target

Taking a look internationally I believe that educators in general are diligently searching for new teaching approaches which lead to a new style of learning. It is obvious that this assumption fits within the context of teaching and learning science, and then mechanics. There is a consensus about the need for the following: a) an effective integration among the disciplines, as well an integration within the topics in each discipline itself; b) transference of knowledge acquired at school to everyday life situations; c) decentralization of teacher and textbook authority; d) teaching thinking skills; e) the responsibility for teaching and learning to be shared between learners and teacher. Those kinds of practices aim at transforming school knowledge from isolated pieces of information into meaningful, applicable and transferable knowledge opening up the opportunity for teaching and learning thinking skills within content (Perkins 1987). I would say that we are witnessing an educational revolution where knowledge conceptualized as static information is leaving the stage and giving place to knowledge conceptualized as design. Perkins (1986, pp. 2-3) writes: "The theme of knowledge as design can break the familiar frame of reference, opening up neglected opportunities for understanding and critical and creative thinking." In this view teacher and learners are invited to think about the purposes, structures, models and arguments supporting the subject matter being developed during the science classes. This sort of practice leads to metacognition which leads to meaningful learning.

Conclusion

The content to be developed in an introductory course in mechanics in the secondary and post secondary levels is an appropriate example to support the idea of teaching thinking skills within content using students previous knowledge. The brief literature review presented in this chapter shows that students come to the science classes possessing their own theories about force and motion acquired from their interaction with the physical world. Instead of ignoring students' previous knowledge, the teacher can use it as a valuable resource for the design of the lesson on that topic, always thinking about the purposes, structure, models and arguments that makes that lesson meaningful and teachable. Students will have the opportunity to compare the scientific view presented by the teacher on that topic with her own ideas and their peers' ideas. This means to see the phenomenon using frames of reference other than her own, as well to think about the purposes, structure, models and arguments that makes that lesson meaningful and learnable. This practice will lead the learner literally to think about that science topic instead of just memorizing it, and therefore to learn it with understanding. In parallel she will be developing thinking skills, such as reorganization of ideas, supporting her own ideas, recognizing flaws in her own ideas, establishing comparisons, making decisions, taking risks, listening to her peers' ideas, and interpreting them using multiple frames of reference.

The important role played by students' previous knowledge within the learning process is supported by the constructivist model of knowledge. In this view knowledge is constructed by the learner in his mind when he tries to make sense of information input to his sensory system. It seems that this is the current epistemology adopted within the research field of science misconceptions. According to Duit (1993) constructivism has been widely adopted in science education and has been a "driving force in research on students' (and teachers') concepts." (p. 9) The next chapter will be dedicated to constructivism and to cognitive learning theories, such as the generative model of learning (Wittrock 1974) and Ausubel's meaningful learning theory (Ausubel 1968). Both of these theories focus on the importance that students' previous knowledge plays in the learning process.

CHAPTER IV

CONSTRUCTIVISM: A NEW EPISTEMOLOGICAL PERSPECTIVE IN SCIENCE EDUCATION

Introduction

I believe that one of the most intriguing and debated issues related to the learning process has to do with the nature and acquisition of knowledge. Learning and knowledge cannot be thought of separately from thinking, making the three of them links of the same chain. The individual's development, as well as the advancement of society, are directly dependent on knowledge and consequently on thinking and learning.

The search for a theory about the nature and acquisition of knowledge and its implications for human life and society is present as far back as ancient Greece in, for example the dialogue between Socrates and Meno, when Socrates tries to bring out Meno's knowledge using the dialectical strategy. Plato's philosophy of knowledge is present allegorically in the parable of the prisoners in the cave.

Rationalism, empiricism and logical positivism

Rationalism and empiricism are the two main epistemologies developed during the seventeenh and eighteenth centuries. Rationalists such as Descartes, Spinoza and Leibniz held that reason is the true source of knowledge, despite not denying the relative importance of sensory experiences. For the empiricists such as Locke, Berkeley and Hume the true source of knowledge is derived from experience. Therefore the individual's mind is considered a blank slate at birth.

Another less frequently mentioned epistemology within the research field of science misconceptions is the logical positivist epistemology of the mid- twentieth century. With all kinds of qualifications this epistemology could be characterized as the resurrection of Hume's empiricist epistemology. In short the philosophical features about the nature of knowledge and its implications have been ranging between the boundaries of mind and senses.

Behaviorism and cognitivism

While the nature of knowledge has been an epistemological issue discussed among philosophers for a long time, its acquisition through scientific method, i.e., human learning, has been studied by psychologists for a little more than a century. Behaviorism and cognitivism are the two main theories involving studies about human learning. The former was developed in the early part of this century and was replaced by the latter which has been flourishing rapidly since the 1950s. For the behaviorists, to learn was a matter of contingencies present in the external world. There was nothing to do with the mind, fitting the logical positivist/empiricist epistemology. Cognitivism, on the contrary, has the core of its learning theory based on mental processes and, according to Wittrock (1978), in this model the role played by the learner is active and constructive, instead of being considered a mechanistic process. Furthermore, there is an active interchange between the stored and new material to be learned which sustains the presence of the intellectual faculties. In all, this view is in agreement with the constructivist epistemology, since in both the individual has an active role and is the responsible for the creation of his own knowledge.

Piaget's cognitive developmental theory

Although cognitive psychology in America reemerged by the middle of this century (Anderson, 1990), in the 1920s Jean Piaget initiated his studies in Switzerland aiming to develop a model of how children learn based on a cognitive theory of children's mental processes instead children's behavior.

Piaget's cognitive developmental theory has an important role vis-à-vis the philosophical issues in epistemology as well within the field of psychology. Actually in parallel to his cognitive developmental theory which contributed a great deal to the replacement of behaviorism, he also developed an epistemological theory. Many researchers working with science misconceptions who have adopted the constructivist view of knowledge agree that this model of knowledge is an outgrowth of Piaget's genetic epistemology.

Indeed according to Kamii (1979), Piaget's theory was the product of his disagreement with both rationalist and empiricist views of knowledge. For Piaget the child constructs her own knowledge, piece by piece, as an attempt to explain and make sense of the events occuring in everyday life. Fig. 4.1 shows the interrelation between Piaget's epistemology and rationalism and empiricism. Piaget's theory is represented by the exterior circle encompassing the two other circles representing, respectively, rationalism and empiricism. The common area between empiricism and

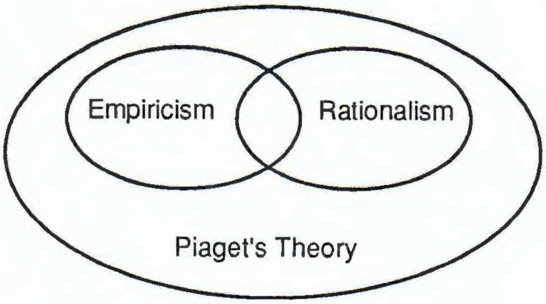


Fig. 4.1 How Piaget's theory relates to rationalism and empiricism (Kamii, p.35)

rationalism represents the common points of both epistemologies, i.e., rationalists recognized the importance of the senses; empiricists admited the importance of reason. In the epistemology developed by Piaget sensory input and reason are interdependent, that is one does not exist without the other. The individual's mental structures are formed through the amalgam of both sensory experiences and cognition basically through two processes of learning. Assimilation, involves the integration of new experiences into the learner's mental structures, and accommodation requires a modification of previous mental structures in order to be consistent with new experiences.

Science, Learning Theories and the Constructivist Epistemology

Science has been one of the most explored areas for the development and validation of theories about knowledge and consequently of models of the processes of both learning and thinking. Within the domain of science, science misconceptions have been chosen by psychologists, philosophers and educators as the topic of their research.

At the present time, constructivism is the general tendency within the education community, particularly in science education in the research field of science misconceptions. Duit (1993) divides the members of "the constructivist party" into three major categories. One is composed of individuals who were constructivists even before they already knew that their ideas were coincident with this epistemology. Another are the ones who claim themselves as constructivists, but whose adherence to the party is just a superficial one. The last group includes those who share the philosophy inherent in the model, but do not accept being labeled as constructivists. This epistemology is proliferating among philosophers, educators, cognitive psychologists and is the epistemological foundation for the studies of science misconceptions.

Duit (1993) calls it a "heterogenous movement" because it lacks a formal definition and is controversial in the education community. This model of knowledge envisions the learner as an active agent whose mind is not a tabula rasa. On the contrary it is always alert and trying to understand and interpret a new situation in the light of her frame of reference and then attribute a subjective meaning to it. von Glasersfeld (1983) said "children, we must never forget, are not repositories for adult 'knowledge' but organisms which, like all of us, are constantly trying to make sense of, to understand their experience." (p. 61)

Before going further, just to illustrate the assumptions made above, I would like to report an experience that happened last winter (winter of 1993) with my five-year old daughter, Maria Carolina. After a snowstorm, high temperature, rain, and then very low temperature, all the streets were covered with a thick layer of ice. I was driving when she said: "Be careful Mom! The car is going 'faster' because the ice makes the ground very slippery; there is nothing to grab the tires, so even if you use the brakes the car is not going to stop." I assume that this assumption was constructed inside of Maria Carolina's mind as an attempt to make sense about a situation never experienced before. This experience might be one of the first among several "constructions" about friction and its consequences on moving objects in Maria Carolina's life.

I would split this event into two stages: a) the body (the senses) transmitted to her a different sensation never experienced before about how the car was moving; b) in the next step the mind (reason) was promptly activated to establish the causes and consequences of this new event, i.e., the construction of a meaning for the experienced situation. This event leads me to conclude that knowledge occurs through the amalgam of sensory data and reasoning with a high level of consciousness.

In this process of attributing meaning to events taking place in the natural world, the development of concepts such as "force" and propositions such as that "motion implies force" arise, and become the foundation of the everyday and normal reasoning of individuals. Vygotsky says that this kind of idea originates from the individual's own reflections about the natural world and calls them spontaneous concepts (Vygotsky 1986, p. xxxiii). When these concepts undergo the intervention of formal instruction another sort of idea develops, giving rise to what he calls scientific concepts. For him, scientific concepts are not assimilated passively. Instead they go through a process of substantial development depending on the individual's general ability which is associated with the level of spontaneous concepts he possesses. Finally Vygotsky concludes: "Spontaneous concepts, in working their way 'upward', toward greater abstractness, clear a path for scientific concepts in their 'downward' development toward greater concreteness." (Vygotsky 1986, p. xxxiv).

<u>Ausubel's meaningful learning theory</u>

Meaningful learning theory is a cognitive learning theory developed by Ausubel (1968) to contraste with rote learning. Ausubel's model of learning has been widely adopted among science educators in general and specifically by the group involved with research in science misconceptions (Novak 1987, Duit 1993). Meaningful learning happens when the learner, through a conscious effort, is able to relate new learning to prior knowledge . In rote learning the new knowledge does not relate to prior knowledge. Therefore it is arbitrarily incorporated in the individual's cognitive structure without any relevance and meaning.

According to Novak (1977, 1985) Ausubel's model of meaningful learning is a process of constant interaction between what the learner already knows and new learning. This means the new knowledge is not simply added to the already existing knowledge, but integrated with it. This principle is based on three major ideas. a) The subsumer is the anchoring concept or proposition for the new knowledge that is going to be incorporated into the individual's cognitive structure. I see science misconceptions as the subsumers within the process of learning science, e.g., the everyday experience that "motion implies force" is an anchoring proposition for the acquisition of Newton's laws of motion. b) Progressive differentiation is the process subsumers undergo in the presence of new knowledge, i.e., new linkages are formed between and within prior and new knowledge. The student will confront the two propositions about motion, his own and the scientific one, which enables him to find the flaws in his proposition "motion implies force." c) Integrative reconciliation occurs when the meaning of two or more concepts or propositions are distinct and/or in conflict. They will be integrated to give rise to a new concept. In this case after acquiring a satisfactory level of understanding about Newton's laws of motion the student might be able to reformulate his proposition "heavier objects fall faster than lighter ones." In both meaningful learning and Vygotsky's theory about the formation of concepts the interdependence of prior knowledge, which develops from the individual's interaction with the external world, and formal knowledge, which develops from the intervention of formal instruction, are emphasized as a decisive factor within the learning process. My proposal that science misconceptions (student's prior knowledge) are a valuable source for the acquisition of scientific knowledge (scholastic instruction), e.g., Newton's laws, instead of an obstacle, is based on the statement of both theories cited above.

It is relevant to call attention to the similarities between Ausubel's meaningful learning theory and constructivism. Both emphasize the learner's active construction of knowledge. This fact is highlighted by Novak (1987) who argues the relevance of having a cognitive theory of learning supported by a contemporary epistemology (constructivism). He says: "Since the creation of new knowledge is a 'learning' phenomenon on the part of the creator, we should expect congruence between a valid epistemology and a valid psychology of learning." (Novak 1985, p. 195). This can be inferred about Ausubel's meaningful learning and Vygotsky's ideas about concept formation: in both cases the individual takes an active role within the learning process, being the agent responsible for the generation of his own knowledge. In short the constructivist epistemology is present in Vygotsky's ideas about concept formation as well as in Ausubel's meaningful learning,since both emphasize the learner as the generator of his own knowledge.

Generative learning theory

The generative learning theory is another model of learning adopted among investigators in the research field of science misconceptions (Osborne and Wittrock 1983; Freyberg and Osborne 1985). It was developed by Wittrock (1974) and has its origin in Ausubel's cognitive psychology (Novak 1985). In this model, as well as in Ausubel's model, the key element is the learner's prior knowledge. Wittrock states: "To introduce the generative model, let me begin by stating its fundamental premise, which is that people tend to generate perceptions and meanings that are consistent with their prior learning." (1974, p. 88). In this model the learner's construction of meanings is a fundamental factor for learning with understanding. When the learner is exposed to new material through listening, reading from textbooks, observing or doing experiments, she needs to generate a model about this incoming information in such a way that it makes sense to her according to the knowledge she already possesses stored in her long-term memory. Finally, after this linkage between prior and incoming knowledge the latter will be encoded in her long-term memory. Fig. 4.2 shows the central role played by long-term memory in this model of learning and its operation (Osborne and Wittrock, 1983).

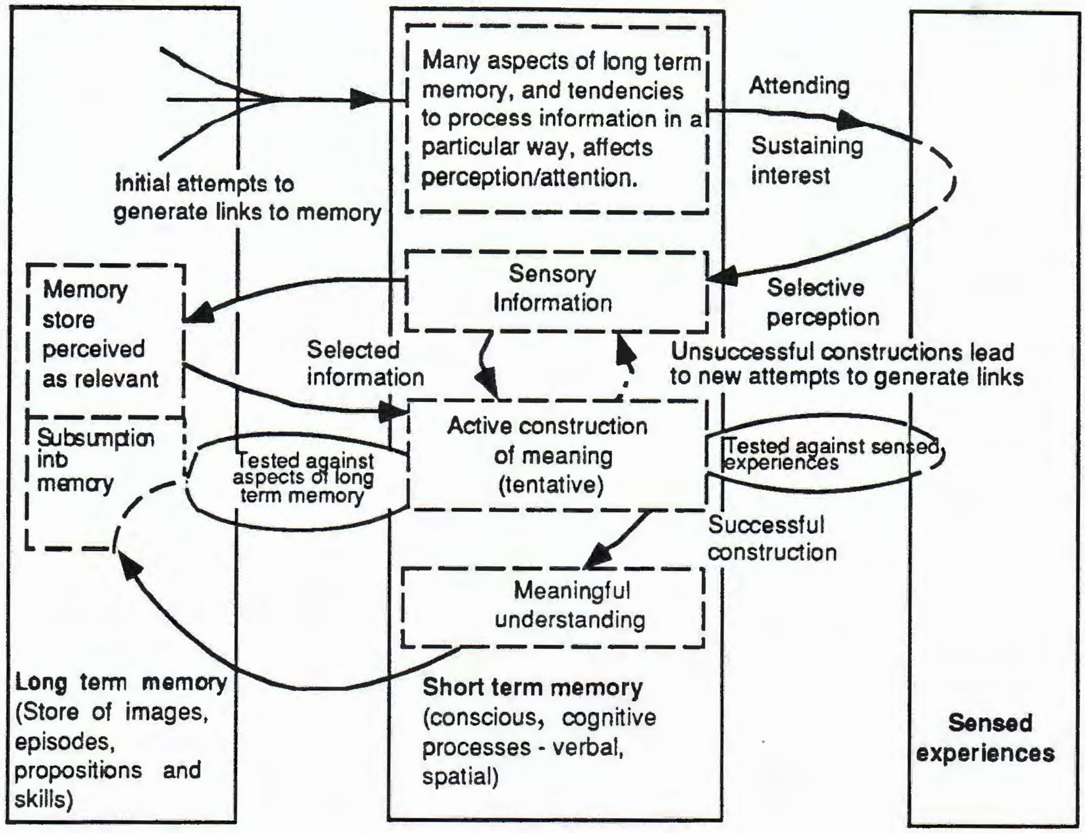


Fig. 4.2 Diagram representing the Generative Learning Model (Osborne and Wittrock 1983, p.493)

It is beyond the scope of this work to discuss in great detail both models of learning cited above, but it seems to me that the degree of similarity between them is significant. In both Ausubel's meaningful learning theory and the generative model of learning the learner's prior knowledge is emphasized as being the foundation of the model. Furthermore their fundamental premise is that learning with understanding happens only when the learner is able to construct meanings for the incoming information that makes sense to him, and this is facilitated by the linkage between prior and new knowledge. It is a dynamic process where the individual's cognitive structure is always changing because of the constant exposure to new experiences and their interaction with previous ones. But it is relevant to point out that the individual's learning is not governed by external factors like the environment, but it is from the interaction of the individual's own thinking and environmental sources that new enhanced cognitive structures will evolve. These assumptions show that both models have their epistemological foundation in constructivism.

Finally, it seems to me that most of what was discussed above are variations of Piaget's ideas about learning especially regarding the ideas of assimilation, accommodation and equilibration.

Assimilation occurs when the individual applies a piece of knowledge he already possesses, i.e., that is already part of his cognitive structure, to make sense of a sensory input. To me this is when a frame of reference plays an important role, because it is very likely that two individuals are going to interpret and then assimilate the same experience differently when they have different frames of reference.

Accomodation occurs when the individual experiences some difficulties within the process of assimilation, i.e., the new information she is experiencing does not fit her preexisting knowledge, causing a disequilibration between both. In order to make sense of the new information some pieces of her prior mental structures need to be modified to achieve a state of equilibration (or adaptation). Novak (1985) who has been developing his research based on Ausubel's cognitive theory acknowledged some similarities between Piaget's and Ausubel's view on cognitive development (Novak 1977).

<u>Appleton's learning model for science education</u>

I believe that the learning model developed by Appleton (1993) encompasses everything that was discussed up to this point in a neat and clear manner as represented in Fig. 4.3. In this diagram the process of assimilation is shown in Exit 1, and accommodation is shown in Exit 2. The Exit 3 shows a situation commonly described in the findings from studies about science misconceptions. The misconception remains in the learner's mental structure without any change, despite formal instruction on that topic, because there is no interaction between the previous and new ideas taught in the science class. Actually the formal knowledge will make sense

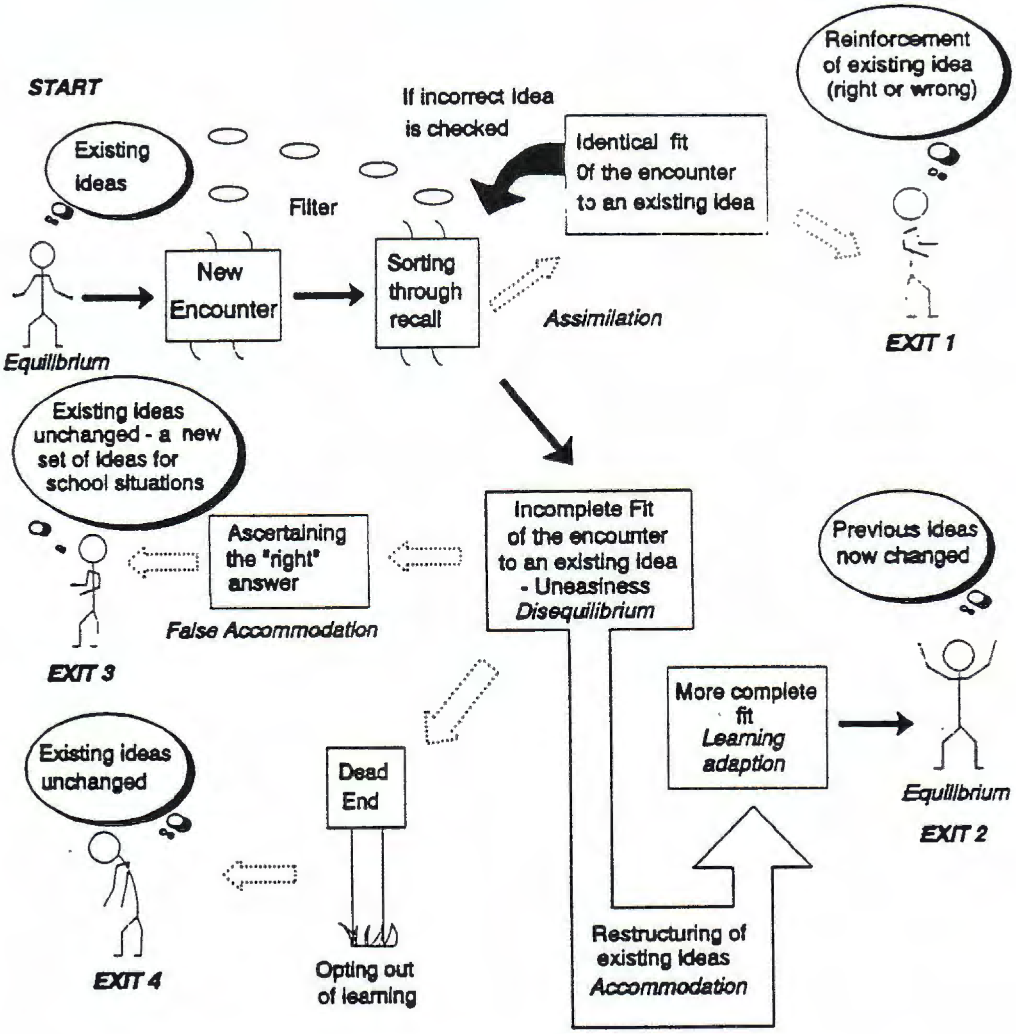


Fig. 4.3 Appleton's schematic representation of the learning model for science education (Appleton 1993, p. 270)

only for the school context, because it is rote learning. Its acquisition is a verbatim memorization (Ausubel 1968). This fact explains the lack of conceptual understanding shown by straight A students on some topics in physics, for example. Exit 4 represents a total absence of knowledge acquisition, not even rote learning. As noted by Appleton, in this case the learner "opts out of the learning experience." (1993, p. 270) It is relevant to note that the epistemology adopted in this model of learning is the constructivist model of knowledge.

Radical constructivism: a brief overview

It seems to me that the best try at outlining a reasonable depiction of radical constructivism is to paraphrase von Glasersfeld (1981) to whom this epistemology has been accredited.

> Radical constructivism, thus, is *radical* because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all and finds himself in full agreement with Piaget, who says, "Intelligence organizes the world by organizing itself." (p. 24)

From the assumption above, the relation between an individual's ideas and reality is not absolute, i.e., the reality is cast according to the individual's view based on his experiences. Therefore there is no absolute reality. Reality is not something immutable and objective that stands there to be discovered by the human being. On the contrary the human being in trying to make sense of the external world is going to construct a subjective reality that fits his expectations, needs and goals. In short this view leads to the conclusion that the relationship between individual and reality is controlled by the former.

According to this epistemology, learners are viewed as inventors instead of discoverers of their own understandings about natural phenomena in the world and this happens with purpose and consciousness. It does not matter if the learner is listening, reading, observing or manipulating new information, the understanding of this information will be an exclusive creation of the learner, i.e., he will be the one responsible for the creation of a mental model about that experience.

The individual does not behave like a mirror which reflects information received from her sensory inputs. Instead these inputs undergoe a careful mental evaluation in an attempt to make sense of them before they are incorporated into cognitive structures. This is "a search for a *fit* rather than a match with reality" Bodner (1986, p. 874).

This focus on a fit rather than a match is one important point focused on by von Glasersfeld (1981) and illustrated by his example about the key and the lock. He says that a key fits only if it opens the lock. The concept of fit is an attribution inherent in the key instead in the lock. This metaphor leads to the conclusion that in radical constructivism each individual constructs her private view about reality as an attempt to organize and make sense of the message received from her sensory inputs.

I will conclude this chapter in the same way I began by quoting von Glasersfeld:

> ... radical constructivism itself must not be interpreted as a picture or description of any absolute reality, but as a possible model of knowing and the acquisition of knowledge in cognitive organisms that are capable of constructing for themselves, on the basis of their own experience, a more or less reliable world. (1981, p. 39)

Constructivism, Science Misconceptions and Critical and Creative Thinking

Contemporary education aims to prepare the individual for life. Within this context, science for example, should be taught in such a way that among other factors learners feel motivated to learn because they are able to make the linkage between acquired knowledge in science and everyday life. This means having the opportunity to demonstrate and use their knowledge in meaningful ways. In short, to learn means to construct knowledge that is going to be useful, viable and helpful, i.e., transferable to practical situations of everyday life.

On the other hand it is out of the question to design a curriculum including all possible sorts of situations that an individual is going to face during his lifetime and the respective rule-of-thumb procedures for their solutions. So the rule here is like the adage. To better help someone who is hungry we should teach him how to fish instead of giving him a fish. It seems to me that transfer will become viable if and only if the development of skills in critical and creative thinking is fostered for teachers and learners. Since in the curriculum there is no such specific subject as a discipline like mathematics, geography, physics and so on, the teacher should generate a classroom environment that elicits the development of such thinking skills.

Fortunately in the case of science, and especially physics, the teacher has a valuable resource, science misconceptions for developing student's understanding of thinking. Science misconceptions can be widely explored during the learning process for the development of skills in critical and creative thinking which in turn are going to help the learners to overcome their misconceptions, i.e., to undergo self-conscious change.

This can occur if during the learning process the teacher does not ignore the ideas that already exist in the learners' mind. On the contrary she needs to help the learners bring out and share their personal understandings about the topic in the science classes. Speaking, writing and listening are excellent ways to lead learners to realize that every single input to the senses can be framed differently in the mind of the observer. Furthermore in this exercise learners can look at their own beliefs as observers, which means to think about their own thoughts.

Within the research field of science education researchers have developed techniques like analogical reasoning (Clement 1987, Brown and Clement 1989) and concept mapping (Novak 1984, 1985, 1987) whose main purpose is to help teachers and learners to overcome science misconceptions through a process of self awareness. This will lead to genuine conceptual change, which means learners making sense of their own knowledge. My idea is to use these techniques to foster the development of solving problems using multiple frames of reference.

These two techniques can generate the opportunity for engaging students in a peer group discussion, also called dialogical thinking, a technique widely applied in the critical and creative thinking field. It is an important and powerful strategy fostering the development of abilities in solving problems using multiple frames of reference. Those are the issues to be presented in the next chapter.

CHAPTER V

TECHNIQUES TO DEVELOP AN UNDERSTANDING OF THE CONCEPT OF FRAME OF REFERENCE

Introduction

As shown in Fig 2.2 in page 17, the number of studies concerned with strategies, techniques and pedagogical methodologies to deal with science misconceptions was limited in the 1970s. The number increased significantly and steadily from the beginning of the 1980s.

It is important to bear in mind at this point that the constructivist epistemology is being widely adopted by researchers in the field of science misconceptions who share a common view about conceptual change. This process happens inside the individual's mind with self awareness of the previous ideas and evaluation of their consistency with evidence. Duit (1991) summarizes the constructivist view as holding two basic principles: "1) learning is an active construction process; and 2) learning is possible only on the basis of previously acquired knowledge." Nevertheless, as pointed out by Strike (1987, p. 484) "people often seem to learn by listening to what others say." I would argue that they learn "by" listening, but not necessarily "what" they listen to, because listening and learning are not so directly connected.

According to the constructivist model of knowledge acquisition there is a stage between listening and learning in which the student interprets the information based on his previous experiences. Therefore, the knowledge that is going to be incorporated is not necessarily exactly what the teacher said. It is how the learner makes his own sense of that according to his frame of reference because the learner is in charge of what he is going to learn. The teacher's role is to convey the information to the learner, but there are different ways to convey information. The teacher needs to seize upon powerful strategies which will enable the learner to process and frame the information under different angles, which means adopting different frames of reference. The teacher needs to cause metacognition in the learner, i.e., the learner needs to think about his own thinking.

Among techniques being developed in the field of science misconceptions aiming to detect and overcome them are the use of analogical reasoning and concept mapping. It is my view that the constructivist epistemology is the philosophical foundation supporting these two techniques because in both of them the learner is going to have control of what he is learning, and therefore make his own sense of the subject matter being discussed.

Analogical Reasoning

It is an acknowledged fact that analogies play a very important role in science and that they have been responsible for generating new scientific theories. Usually scientists start thinking about their novel theories by hypothesizing upon imaginary models which will lead to the formulation of laws and theories that will become part of scientific knowledge. An example is the billard ball model for gases (Clement 1988).

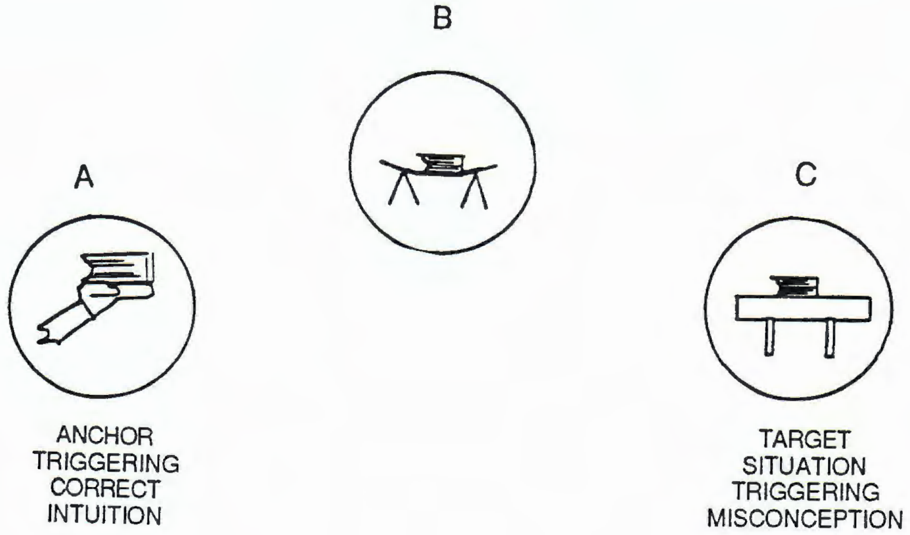
In the field of science education, research has been suggesting the important role of analogical reasoning for overcoming students' science misconceptions (McDermott 1990; Clement 1987; Brown and Clement 1989).

Although this is not explicitly mentioned in the field of science education, analogical reasoning plays an important role in the development of skills in critical and creative thinking. Lipman (1987) holds that making connections and making distinctions are the simplest but most fundamental skills for the development of higher order thinking, because they enable the thinker to begin to group, classify and define. I would add that the solution for a problem will be found only after the problem becomes defined. The use of analogies encompasses all those skills whether they are verbalized or not, and helps lead the individual to a metacognitive process. I believe this comment supports my proposal about the positive role science misconceptions could play within the teaching-learning process if used properly. They should not be ignored by the teacher, but on the contrary they should be brought out and handled by techniques such as analogical reasoning that help the learner to confront his view with the scientific view. This means to give the learner the opportunity to reflect about his own thinking and become an active agent in the teaching-learning process, instead of being a passive recipient.

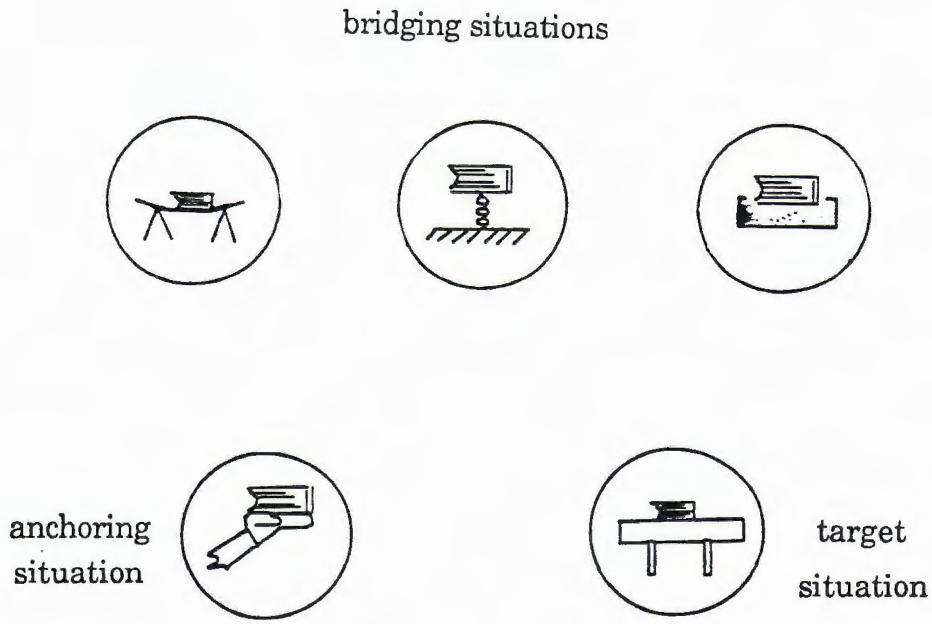
Terminology

Clement (1987) and his associates have been studying the role of analogical reasoning in promoting conceptual change in the learner's prior knowledge, acquired from everyday experiences and in disagreement with the scientific view (a misconception). According to Clement (1987, 1989) the scientific concept to be introduced to the learner is called a target situation. An example of a target situation (Clement 1987; Minstrell 1982) is a book at rest on a table, used to teach the students that there is a force acting on an object resting on a static rigid body.

An anchoring situation is a situation presenting the same feature as the target situation using different objects (an analogous situation), introduced by the instructor to the students. It is supposed to lead the student to a correct intuition. An example of an anchoring situation for the target situation of the book-on-the-table is an individual's stretched hand holding a book. Students do not accept the idea that the table exerts a force on the book (target situation), but they admit that the hand exert a force on the book (anchoring situation). To make the analogy proposed between the target and anchoring situations more plausible, an intermediate analogous case called a bridging analogy should be proposed by the instructor. In the case of the book-on-the-table situation the idea of a book on a thin flexible board was introduced as the bridging analogy. The target situation, the anchoring situation, and the bridging analogy are shown in Fig. 5.1a. More than one bridging analogy can be suggested to the students as shown in Fig. 5.1b such as: a book on a spring, a book in a foam rubber pad, as well as thought experiments like a microscopic model of rigid objects whose microstructure is composed of atoms linked by spring-like bonds. The sequence of events proposed to the students is important, i.e., the first question is about the table exerting a force on the book (target situation). Then the book on the stretched hand (anchoring situation) is introduced followed by the bridging analogies. This sequence of events will engage students in a lively peer group discussion, which fosters the development of thinking skills such as : a) presenting their opinions based on convincent arguments; b) having criteria for evaluating and weighing their peers' viewpoints; c) evaluating a situation through comparisons; d)metacognition; e) reorganization of ideas.



(a)



(b)

Fig. 5.1 Schematic representation of analogies with the target and anchoring situation (a), and bridging situations (b) (Clement 1987, p.87)

Metaphors

Before concluding this section about analogical reasoning, I would like to make some comments about metaphors and their role within this context. They are as valuable as the analogies in the teaching-learning process in terms of overcoming science misconceptions and at the same time teaching thinking skills. However according to Duit (1991) "An analogy *explicitly* compares the structures of two domains; it indicates identity of parts of structures. A metaphor compares *implicitly*, highlighting features or relational qualities that do not coincide in two domains" (p. 651). The point is that metaphors and analogies are not interchangeable, although they are very similar regarding their role as techniques promoting the desirable conceptual changes in the learner's mind. Another important point regarding metaphors is that they foster the individual's reasoning functions, because most of the times a metaphor is not immediately understood. On the contrary they need to be unwrapped. Therefore metaphors as well as analogies, can be valuable tools to develop skills in critical and creative thinking, because they lead the learner to learn how to make connections and distinctions in two domains. This practice fosters the ability to approach a situation using multiple frames of reference which means to develop abilities for solving multilogical questions (Paul 1987).

Conclusions

Clement (1988, p. 581) states: "An interesting characteristic of analogical reasoning lies in the paradox that by seeming to move *away* from a problem the subject can actually come *closer* to a solution." I see this statement as implicitly emphasizing the importance of using multiple frames of reference when approaching a situation; that is, when the individual is searching for a solution to a given problem she needs to be able to move away from it and look from the outside as a spectator.

The use of analogies fits this context of the generation of multiple frames of reference, leading the learner to develop skills in critical and creative thinking. He needs to manipulate the information and ideas inferred from each context and transform their meanings in order to synthesize, generalize, hypothesize, and come up with conclusions. Besides, the use of this technique leads to another technique, Socratic discussions (Clement 1988), which gives to the learner the opportunity to learn how to structure and organize her ideas in order to make them understandable to the audience. This practice leads the learner to have criteria to evaluate her beliefs which will help her to find out the differences and possible flaws between her conceptual ideas about the topic and the scientifc view.

Concept Mapping

Concept maps are schematic representations showing the interrelations that exists among concepts within a context. Within the teaching and learning context they can be defined as diagrams representing a piece of knowledge through the arrangement of its concepts in a hierarchical order. This technique is a learning strategy developed by Novak and his associates as part of a research program at Cornell University since 1964 (Novak and Gowin 1984; Novak 1985, 1989). Concept mapping has its theoretical foundation in Ausubel's cognitive learning theory (Ausubel 1968) and constructivism, both presented in Chapter IV of this thesis.

Fig. 5.2 shows a concept map representing students' previous ideas on pressure, weight and gravity (Mayer 1987, p. 302). Taking a quick look at this concept map we can identify some propositions such as "air has no weight," "air may fill vacuum," which are in disagreement with the scientific view.

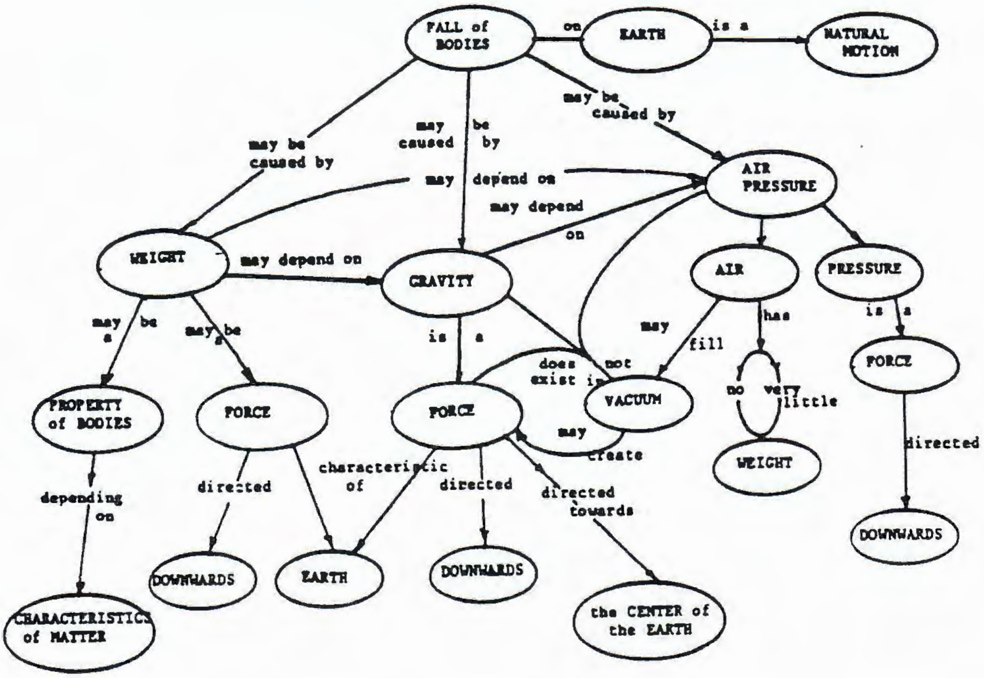


Fig. 5.2 Concept map representing students' prior ideas about the concepts of pressure, weight and gravity. (Mayer 1987, p. 302)

Concept mapping and science misconceptions

Within the domain of science misconceptions, concept mapping has been found to be a powerful strategy to detect students' misconceptions, as well as to overcome them, because it is a visual feedback of the learner's thought available to the teacher. We can make an analogy with how much easier is for someone to walk or drive in a place never visited before when she has a map of that place. The same can be said about having a map of one's thought about a specific subject matter. Novak (Novak and Gowin 1984) defines a misconception as being:

> a linkage between two concepts that leads to a clearly false proposition or by a linkage that misses the key idea relating two or more concepts. ... Research suggests that the best method for correcting a misconception is to identify one or more missing concepts that, when integrated into the individual's conceptual framework, will obliterate the misconception. (p.20)

Other benefits brought by the use of concept mapping to the teaching-learning process in science are: a) the opportunity given the learner to talk about science using his own language; and b) the organization of the learner' knowledge in a meaningful way (Roth and Roychoudhury 1992). When constructing a concept map about a subject the learner is doing metacognition. Moreover he is learning how to organize his concepts hierarchically, which I see as a means to develop an ability to select concepts according to their priority within the context in which they are being used. This exercise will lead the learner to find out that the same concept can assume a different meaning according to the context in which it is inserted. This leads to an awareness of the importance of using multiple frames of reference when approaching a situation. Concept mapping is a strategy fitting the current purpose in education, i.e., teaching thinking skills within a context like history, mathematics, physics and so on, instead of teaching it in the form of a stand-alone course (Perkins 1987).

Terminology and procedures

Concept maps are a graphic representation of an individual's cognitive structure about a specific topic. They represent the relationships between concepts in the form of propositions. According to Pines (1985, p. 108) "Concepts are regularities labeled with words and employed in thought and communications." Words like "force," "motion," "acceleration" are examples of concepts. "Propositions are representations in memory of facts or beliefs ...they are single facts." (White 1985, p.52) Motion implies force and acceleration is proportional to net force are examples of propositions. There are no rigid rules for constructing a concept map, but it is important to be aware about the terminology used and some general instructions. The list below is an example of general instructions for drawing a concept mapping (Moreira 1987; Novak and Gowin 1984):

a) Make a list of all concepts involved in the unit being studied. For example in mechanics some of the concepts are force, speed, acceleration and so on.

b) Write the concepts on a piece of paper having them ordered hierarchically. This means that the most general concepts should be at the top of the map followed by the less general concepts at the bottom according to your own view.

c) Connect the concepts which you might think are related using lines. Write on these lines words that show how the concepts are related to each other according to your view. These lines are called "linking words."

d) A "propositional linkage" is made up of two connected concepts. Sometimes there is the possibility of establishing a linkage between concepts that are not associated directly. They might be an insight about prior ideas. They are lines named "cross links."

It is important to point out that a set of concepts can give rise to more than one valid concept map depending upon the person's frame of reference, as well the context in which the set of concepts is being applied. It is my view that this point plays a very important role within the teaching-learning process, because it can be an anchoring point for the teacher to demonstrate to students the important role played by a frame of reference when we are trying to externalize our thoughts as well as approach a situation. This is very appropriate in terms of generating an atmosphere for a thoughtful dialogue among teacher and learners.

In a study conducted by Roth (1992), among other strategies he used concept mapping in an attempt to bridge the gap between scholastic knowledge and real life. One of the students' activities was to construct a concept map for planning and reporting their laboratory activity about hydrodynamics. Fig. 5.3 (Roth 1992, p. 309) shows an example of a concept map for planning and reporting students' laboratory activities about hydrodynamics.

The main question to be answered during the experiment was: "How does the velocity-time graph of an object dropping through a liquid change with the shape of the object?" The associated words for drawing the

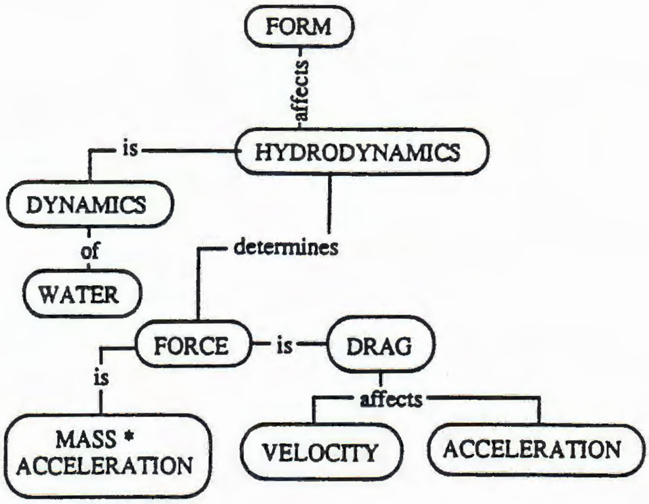


Fig. 5.3 Concept map representing a student view about basic concepts about hydrodynamics (From Roth 1992, p. 309)

concept map were: aerodynamics, hydrodynamics, density, friction, surface area, acceleration, speed, time and form/shape.

According to Roth (1992) doing experiments in the lab, i.e., hands-on activity, is necessary, but not sufficient, to generate meaningful learning. Hands-on activity needs to be associated with a process of reflection about what is being done. That is, the learner needs to be able to reflect about his own thinking. To that end learners need to be exposed to techniques that are going to create this opportunity. Among other techniques, concept mapping was adopted as a mean to engage the students in a metacognitive process. Roth reported that students were asked to evaluate this novel approach to learning physics and the results were very favorable, indicating a very positive attitude from the learners.

Conclusions

> The rapid shifts in the methods of mathematics education that have taken place in the last few decades ... did not work the miracles that were expected of them ... Now there is disappointment, and this disappointment -- I want to emphasize this -- is not restricted to mathematics education ... there is only one exception that forms a remarkable contrast: the teaching of physical and, especially, athletic skills. (von Glasersfeld 1983, pp. 41,42)

After having made this statement, von Glasersfeld proposed a sound analogy to justify why the teaching of physical and athletic skills has been succeeding while other academic areas have not. Methods ranging from the most sophisticated to the simplest such as slow-motion videotapes are valuable resources used for teaching physical and athletic skills, because they give learners the opportunity to see and observe themselves acting, i.e., learners have a visual feedback of their own performance. This situation enables learners to be in control of their own action. They literally become spectators of themselves, which ensures a very accurate evaluation of their own performance leading to a recognition of their weaknesses and strengths.

In other academic areas like physics, there is no way to apprehend with a camera what is going on inside the learner's mind, i.e., the mental operations that lead to the formation of concepts, propositions and schemata. The teacher must be the one to create means to foster metacognition during the learning process.

Looking at Fig. 5.3 we see that a concept map can be considered a picture of the learner' mental operations on the topic being learned. Therefore following the analogy suggested by von Glasersfeld, a concept map will be a "re-presentation" of the earner's mental perfomance giving him the same opportunity as athletes have to be in control of their own learning which makes them aware of what they are doing and why it is being done.

It is obvious that concept mapping does not represent the solution to all the problems existing in the learning and teaching of science, but it is a relevant contribution for the achievement of teaching thinking skills through the content of science.

Dialogical thinking

It is undeniable that we are living at a threshold in education. It is the beginning of a new era following the advancement of science and technology in society. Paradoxically, educators have gone to the far past aiming to bring to the present techniques like Socratic dialogue for helping both teacher and learner in a cooperative effort to foster the development of thinking skills. Lipman (1987) states that"Socratic dialogue, in which the teacher helps the learner bring to light what he or she apparently already knows and in which both teacher and student explore and discover together, has been a particularly interesting dialogical procedure." (p. 157)

This practice, also called dialogical thinking has been a driving force in the context of critical and creative thinking, having as one of its major aims (Paul 1987) to lead students to see and think about a situation from multiple frames of reference (Paul 1987).

The classroom: a suitable scenario for dialogical thinking

If someone is asked to close his eyes and imagine a classroom it is very likely that the scenario is going to be a teacher speaking and students listening. I would say that this is our educational heritage. Fortunately nowadays educators, curriculum developers, teachers, philosophers, psychologists and the society in general are sharing the idea that a classroom has to be the place for students to develop their potentialities to become good and independent thinkers. Definitely the classroom cannot be considered apart from the outside world. On the contrary it has to be a part of our reality because it is under the influence of social forces such as diversity of social, income, and racial class as well as affective and psychological differences like motivation, interest, intelligence, etc.

Taking a look at Fig. 5.4 (Lipman 1987, p. 154) it seems to me that those parameters involved within the teaching-learning process can be gathered and used as resources to develop skills in critical and creative thinking within the practice of dialogical thinking. This practice leads the learner to have conscious control of her cognitive and affective functions, such as: a) listening to other ideas being critical, but respecting them; b) having criteria for making evaluation and comparisons; c) organizing ideas and supporting them with sound arguments. The model proposed by Lipman (1987) represents a new fashion of a classroom environment where knowledge is gained not only from the teacher's authority, but from a common effort by all members of the classroom community.

Adopting dialogical thinking as a strategy to convey scientific knowledge to students is an example of bringing reality from outside to inside the classroom, i.e., it is an attempt to minimize as much as possible the gap between school and real life. As noted by Paul (1987) most of the real situations faced in everyday life are multilogical, i.e., their definition, analyses and solution are attached to multiple frames of reference.

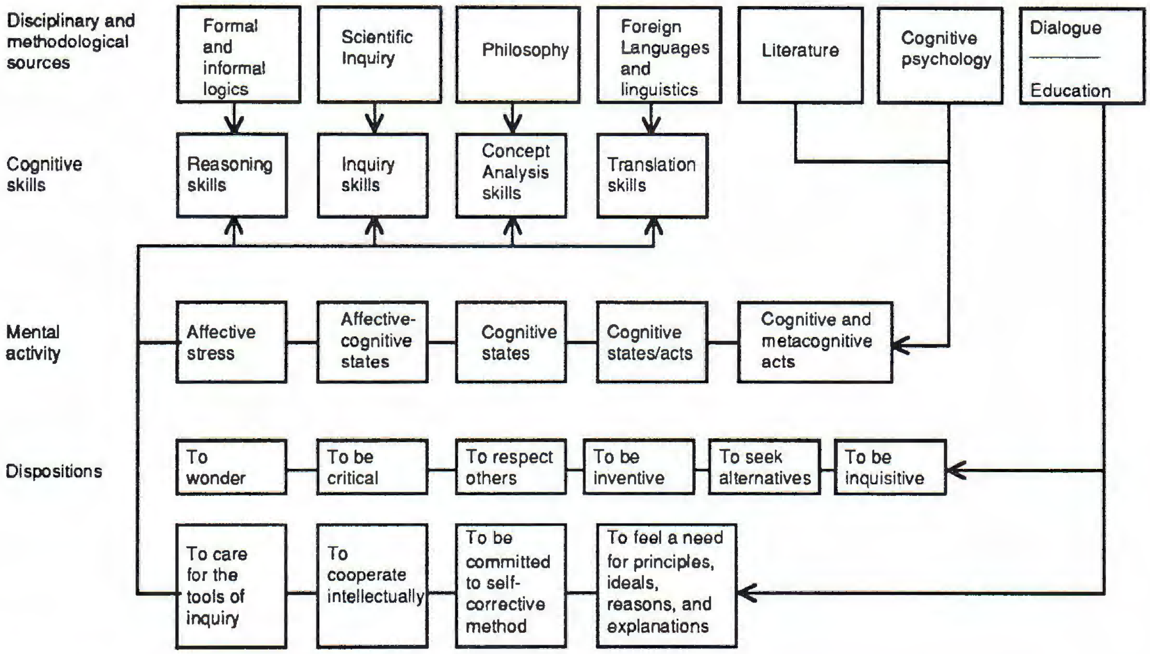


Fig. 5.4 Lipman's diagram of a model of the classroom as a community of inquiry (From Lipman 1987, p. 154)

Conclusions

Although in the literature there is no explicit mention that both analogical reasoning and concept mapping elicit the development of students' thinking skills, it is quite immediately clear that they do. In the case of concept mapping for example, students need to establish a hierarchy among the concepts featuring in the concept map. For that they need to organize, to compare, to establish priorities and, more than that, they need to think about their own thinking.

In analogical reasoning students are directed to perceive similarities among situations occurring in different contexts, e.g., the book-on-the-table and the book-on- the-hand, described above. This means to approach a situation under different frames of reference. Furthermore, both techniques themselves lead to the practice of dialogical thinking, which is highly recommended in terms of decentralizing the teacher and textbook authority within the teaching-learning process. This posture encourages learners to not accept assumptions uncritically just because they came from the teacher or they are in the textbook. Easley (1990) describes the vivid atmosphere generated by a spontaneous peer group discussion when a first-grade teacher made the assumption that gravity is the force that holds things on the earth. Promptly a student argued that was not true because grass grows up, people can jump up, balloons go up and so forth. This kind of situation challenges learners to externalize and share their ideas with peers and calls for more arguments supporting the teacher and textbook assumptions. By the same token it challenges the teacher to be prepared to present sound argument to support his assumptions. Another important point is that this kind of situation triggers the curiosity of other students and certainly others issues will be addressed. At this point students are self motivated, an important factor that helps the teacher explores the theme being studied in depth. This is a realistic example of the urgent necessity of having the classroom transformed into an environment of inquiry as called for by Lipman (1987).

In the next chapter I am going to introduce my experience working with freshmen students during eight weeks when they were attending a physics summer course. The assignments they turned in to me were paragraphs using physics concepts like "force," "mass," "energy," "frame of reference," and so forth and a concept map using 35 physics concepts. This experience does not offer conditions for quantitative analysis, but its qualitative aspect gave me some insights for the design of future research with the purpose of using science misconceptions as an approach to develop thinking skills.

CHAPTER VI

A PHYSICS SUMMER COURSE FOR FRESHMEN

I was finishing my last course in the Critical and Creative Thinking Graduate Program at the University of Massachusetts at Boston when I learned about a summer project in physics at a university in the Boston area. The director of this project was a physics instructor in that institution. He teachs physics in one of the three alternative academic programs for freshmen in that institution. The program is a community of faculty and students interested in exploring new approaches to teaching and learning. This alternative program was established in 1969 as an educational alternative to the regular curriculum and got its permanent status in 1979. In this program the subjects are taught through self-paced tutorials, small seminars, and independent study for the most part. The major goal of this program is to integrate the scientific disciplines like physics, mathematics and chemistry with humanities subjects like philosophy, psychology and so on.

I was very interested in obtaining more information about this program, and I thought that the best way to know more details would be talking with students who opted for taking their first academic year in this program. Talking to two students I had the opportunity to ask them about their experiences and they gave me the following answers: First student: "The papers I wrote were particularly helpful because they encouraged me to think critically about each writer as I read the books. The nicest aspect of taking this psychology course, though, is that it opened up a whole new realm of learning and exploring." Second student: "The physics was much more logical when it was presented with the math that justified it. Physics was also very good because it gave realistic reasons behind why everything works the way it does."

These remarks convey why I became interested in joining this summer course as an observer.

The Design of the Physics Summer Project

This course was taught during 8 weeks, covering the following topics in mechanics:

- Mathematical review
- Kinematics
  - One Dimensional Kinematics: Position, Velocity, and Acceleration
  - Constant Acceleration: Equations of Motion
- Two Dimensional Kinematics
  - Parabolic Motion and Introduction to Vectors
  - Newton's Second Law
- Forces
  - Force Diagrams and Newton's Third Law
  - Applications of Force Laws
- Circular Motion; Work and Energy
  - Kinetic Energy
  - Potential Energy
  - Power
- Momentum and Vectors
  - Conservation of momentum
  - Impulse

The main goal in this project was to get the students who would be freshmen in the regular undergraduate program in the Fall 1992 semester acquainted with the system and philosophy of the school, as well as bringing them up to a minimum level in physics.

Sixty students were enrolled in this project, divided into seven major groups: A, B, C, D, E, F, G (with ten students in each group). The criteria used for classifying them were: a) the results of a mathematics diagnostic test; b) the results of a physics intuition test; c) if the student took any course in physics at high school; d) SAT scores. Each group above was divided into subgroups of five students: A1 and A2; B1 and B2 and so on.

The same basic topics were covered in each group. The main differences among groups were the mathematical sophistication employed, types of problems introduced, and degree of conceptual emphasis on physical concepts.

The course was designed with the following format:

a) <u>Principal Discussion Groups</u> met three times a week, and were not taught in traditional lectures, but adopted a "workshops style" in which theoretical material was introduced hand in hand with active problem solving by students. There were three lecturers, therefore three groups: A and B, C and D, E and F.

b) <u>Problem Solving Sessions</u> met once in a week in groups of ten (A, B, C and so on) and once every other week in groups of five (A1, A2, B1, and so on). As the name suggests the students actually worked on problems during the classes, having the tutors answer their questions and having more individual help.

c) Laboratory met every other week in groups of five students, performing preexisting experiments related to the theoretical topics developed in the lectures. They worked in teams.

d) Project met every other week with the project instructor. Students worked in groups of two or three in the design of an experiment of their own choosing to measure one or two physical quantities (depending on the complexity of the experiment) associated with mechanics. They were supposed to look at their immediate surroundings and identify examples of physical quantities which they were introduced to in class and then design some measuring device which would enable them to measure those quantities. The project was divided into four basic stages: i) articulation of the project; ii) design of the measuring apparatus; ii) measurement; and iv) theoretical framework with error analysis. It was due the last day of the course.

e) Weekly handout assignments whose content was: i) readings (usually an article on misconceptions in physics) and a chapter of the text book; ii) 3 problems covering the topic developed in the Principal Discussion Group; iii) weekly discussion about the design of the project; iv) weekly written assignments in which students were asked to write at least two paragraphs using six words from the physics context, such as: "dimension," space, "time," "speed," "velocity" and "acceleration." The instructions were: "You can choose any form you want. For example you could write a story, describe an event, present a dialogue, or illustrate a comic book. Try to use the words in a manner which illustrates their conceptual meanings in physics according to your view."

The students had 7 weekly handouts during the course. For the last one, the 7th, they were asked to construct a concept map using all thirty five words from the course.

f) Evaluation: every other week they had a quiz covering the subject taught. There was also a final exam.

My Role in this Summer Course

My participation in this project was as an observer. The comments I am going to present serve as illustrations of the data presented in the literature review in Chapter III. Although I had participated in all sections, my interaction was much more intense in the sections regarding the paragraphs using the words representing concepts in mechanics and in the drawing of a concept map using all the words from the paragraphs. I also helped with the survey (Appendix A) about the introduction of these two techniques to help them become aware of their misconceptions in mechanics and to develop some skills in critical and creative thinking like: a) transfer of acquired scientific knowledge to new situations; b) recognition of flaws in their hypotheses, using their mistakes as valuable tools for their intellectual and personal improvement; c) ability to support their own ideas; e) ability to reorganize ideas; f) self confidence and risk taking in solving problems. The questionnaire used in this survey is in Appendix A of this thesis.

Writing Assignment about Formal Scientific Concepts and Concept Mapping Assignment

The idea of introducing this writing assigment was to give students the opportunity to externalize their understandings about specific concepts used in elementary mechanics. I believe that this kind of activity also helps to engage students in a metacognitive process.

The paragraphs using words representing concepts in mechanics

At the beginning of the course students were presented with a list of words representing specific concepts used in elementary mechanics. They were: dimension, space, time, speed, velocity, acceleration, kinematics, gravity, parabolic motion, force, mass, dynamics, constant acceleration, equal and opposite forces, inertia, Newton's second law, force, mass, frame of reference, energy, work, power, centripetal acceleration, action/reaction force pairs, kinetic energy, momentum, potential energy, centrifugal force, centrifugal acceleration, conservation of energy, potential energy, impulse, non-mechanical energy, center of mass.

Each week they were asked to take three words from that list which represented concepts that had been formally introduced during the week and two or three words that were going to be formally introduced in the following week. For example, the list of concepts for the first week's writing assignment were: dimension, space, time, speed, velocity and acceleration.

I had the opportunity to read all assignments and my attention was focused on finding out the presence of everyday meaning given to these words representing concepts used in mechanics. It is my view that the example below from Student 1 (written in the early weeks of the course) illustrates this point. In the example below the student used the words "energy" and "power" interchangeably. Moreover, when I pointed this out to her she read the sentences again, reflected for a while, and told me that both words , i.e., "energy" and "power" should be replaced by the word "force."

> ...I was so tired that when we reached Networks I couldn't use energy to pull the door open. It was a simple task but I wasn't in the mood to do that type of work. Although my friend and I both had the power to perform this job I left it up to him because I was feeling kind of weary.

Concept mapping

The last assignment of the course involving the words representing concepts in mechanics was to draw a concept map using all the words.

I had a brief talk with the students and gave them an outline about this technique and some samples as sort of basic instruction in how to draw a concept map. The concept map drawn by the same student, i.e., Student 1, whose sentences were presented in the section above is shown in Appendix B. It seems to me that in the concept map she drew she no longer used the words "power," "force," and "energy" interchangeably. Indeed her concept map show a more accurate conceptual understading which is both clealy and hierarchically organized.

Appendix B also shows concept maps drawn at the end of the course by two other students, Students 2 and 3. These students also showed improvement in their conceptual understading from earlier in the course. Interestingly their concept maps are each unique and used a different hierarchical organization than Student 1. In my view, this supports my claim that people try to make their personal frames of reference and that there can be more than one accurate way of thinking about these conceptual relations. Moreover this situation also supports my claim that this strategy as well as analogical reasoning can be very effective in promoting the development of skills in critical and creative thinking, especially the use of multiple frames of reference.

Remark

The most remarkable fact I observed in this summer course relates to students' performance in their final project. As described above they were to design an experiment for measuring one or two physical quantities associated with mechanics. I was impressed with the variety of ideas as well as the creativity they used in the design of the required measurements for their experiments.

Among them were: the measurement of the angular velocity of a compact disc on a compact disc player, the elastic constant of a rubber band, the amount of force required to break a standard pencil and its angle of deflection as a function of the force applied, the rebound of a volleyball based on air pressures, the velocity of a chair thrown off a building 22 meters tall, the initial velocity of a projectile fired off from a building using a spring cannon, the acceleration due to gravity, the measurement the surface speed of the Charles River, and the volume of a person.

To develop such projects they had to have a deep level of conceptual understanding about the concepts they worked with when they wrote the paragraphs and drew the concept map. I wonder why in their writing assignments, and the multiple choice diagnostic test they had some misconceptions that were not present during their experimental final project. In my view one of the reasons for students' success in their projects lies in the freedom they had to think about the theme as well in the design of the project. I believe that freedom to think about questions is an important factor leading the individual to be engaged in a metacognitive process. During the process students had the opportunity to transfer acquired scientific knowledge to new and real situation which I see as a source of self-motivation. Moreover, they had the opportunity to evaluate their initial hypothesis based in concrete measurements, and in the case of failures they had the chance of rethink the experiment through reorganization of ideas.

Conclusion

I believe that the most important point during this summer project concerns the way students were challenged to confront their previous conceptions about mechanics and the scientific view. According to the constructivist perspective students' prior ideas must be taken into consideration in the design of science lessons. This is an issue that has been addressed and emphasized since long time. The following quotations illustrate this point:

> Though scientific and spontaneous concepts develop in reverse directions, the two processes are closely connected... In working its slow way upward, an everyday concept clears up a path for the scientific concept and its downward development. (Vygotsky 1986, p.194) [first edition 1934]

> The most important single factor influencing learning is what the learner already knows; ascertain this and teach him accordingly. (Ausubel 1968, p. iv)

> Principles of mathetics are ideas that illuminate and facilitate the process of learning... First, relate what is new and to be learned to something you already knows. Second, take what is new and make it your own: Make something new with it, play with it, build with it. (Papert 1980, p. 120)

> Learning takes place not much through the taking in new information or facts rather through the organization and imaginative restructuring of experiences we already have. (Driver 1985, p. 171)

> Education that takes seriously the ideas and intuitions of the young child is far more likely to achieve success than education that ignores these views, either considering them to be

> unimportant or assuming that they will disappear on their own. The ideas of the young child -- the youthful theorist -- are powerful and are likely to remain alive throughout life. Only if these ideas are taken seriously, engaged, and eventually trimmed or transformed so that more developed and comprehensive conceptions can come to the fore -- only then does an education for understading become possible. (Gardner 1991, p. 248)

> Students have not understood much of what they have been told, in part because no one has listened to their preexisting ideas (Yager and Lutz 1994, p. 341)

I believe that the accuracy with which the majority of students designed and developed their experimental projects and drew their concept maps using concepts in mechanics such as "force," "velocity," "acceleration," "energy," "work," and so on, supports the claim of the important role students' previous conceptual understadings play in the learning process. Moreover this approach helps to transform the traditional classroom where the authority is centralized in the teacher and textbook into an environment that fosters students' freedom and autonomy to share their ideas as well to listen to their peers' ideas.

CHAPTER VII

AFTERWORD

The most common claims in the field of science education have been about students' lack of interest in learning science, students' poor academic achievement, and students' lack of skills in higher order thinking.

Parallel to these claims there is a consensus about the importance of taking into account students' previous ideas in the learning process. I believe that this point is a good start for responding to the claims stated in the first paragraph. In making her ideas available the learner is led to reflect about her own thinking, a practice that fosters the development of higher order thinking. By the same token this "sharing ideas" will help learners to develop self confidence, self motivation, and to approach the same issue using multiple frames of reference.

Another important consequence of taking into account students' previous knowledge is the decentralization of teacher's authority. I believe when centralized authority is excessive learners lose interest in the class. Moreover, the teacher should act much more as a facilitator than a transmitter of knowledge, guiding the learners to access the different sources of knowledge and attending their own necessities.

An important point concerns the low degree of attention given to pedagogical theory especially by those in the scientific community who teaches natural sciences at the universities. As a consequence the novice teacher leaves school lacking abilities and knowledge about cognitive theories of learning, teaching methodologies and, most seriously, without having a conceptual understanding about scientific theories. They spent their time during undergraduate studies receiving verbalized instruction which generally leads to memorization of formulas and algorithms. This practice makes the novice teacher far from having the desirable conceptual understanding about the scientific laws and theories. There is a need to have a coherent research program aiming at the development of instructional strategies for the teaching of science at the undergraduate and graduate levels. I heard somewhere the following: "if you know you do; if you do not know you teach; and if you do not know how to teach you teach how to teach."

The professor sometimes when teaching forgets that the scientific knowledge she is trying to transfer to the students is already part of her cognitive structure. The scientific laws and theories seem trivial and obvious to her, as would counting from 1 to 10 be for a preschool child. The instructor does not realize the students' necessity of having the grounds for building a solid and coherent scientific structure on that topic. She also does not take into account students' previous concepts. What usually happens is that few students are able to surmount this gap by their own efforts and to acquire the desirable development of skills in how to think scientifically, which, in my view, is done throughout the process of thinking critically and creatively. The majority of students stay on the plane of rote learning just to cope with the administrative rules of the school for getting their degree. Being a straight A student does not mean being able to talk about science topics with a scientific approach, which means to have a sound and clear conceptual understanding.

This process is a vicious circle where some of those students who succeed might pursue an academic career and then they will start the same process, i.e., taking their acquired scientific knowledge for granted and making their students follow the same path they went through. Finally, to justify this state of affairs there is the necessity to find someone or something to be blamed for the students' failures to succeed in science rather than to find out the basic causes for this effect.

During my seventeen years teaching mathematics and physics at the primary and secondary level in Brazil, it was rare to finish my day without hearing the same complaint coming from some of my colleagues saying that the students reached that degree lacking the necessary knowledge for the present stage. Obviously all the mistakes were addressed to the preceding teacher, curriculum developer, educational system adopted and so forth, because someone needs to be blamed. Just a few of my colleagues were interested and concerned to find out possible hypotheses that could lead them to the design and development of instructional strategies which could defeat the causes. As a further product of the teaching-learning process one obtains thinking minds aware of their strengths and weaknesses to better promote their own improvement as well as to give their contribuition for the improvement of the society.

It is my view that once an individual has already achieved a stable degree of scientific knowledge the path to come back to the origins of how this achievement was acquired is extremely difficult. It is difficult to go back and to figure out how he got there, what were the pedagogical steps he took, what were the techniques he used. It is like learning how to ride a bicycle. Once you learn it you will never forget, but it will be very hard to describe what were the steps followed during the learning process of how to ride the bicycle, and consequently it is difficult to become a master in teaching someone to ride a bicycle. So the issue concerning the teaching and learning of instructional techniques and pedagogical theories should receive more attention in the research field of science education.

The importance of integrating school science and technology is another issue that has been addressed frequently (Hurd 1986). Presently this issue is at the core of science curriculum reforms. This point is highly emphasized in Project 2061 (Yager and Lutz 1994). I believe that this sort of curricular integration is going to empower the idea of teaching critical and creative thinking within content. Students and teachers will have the chance to pose questions, build hypotheses, and recognize and identify problems in their community and then present suggestions for solving them.

Taking a look at how fast the scientific and technological areas have been going through changes, advancements and breakthroughs it is just amazing. However in the area of education, mainly the process itself is the same since a long time ago. I hope that all these movements toward an education more centered in the learner become more and more strong and receive contributions from all communities.

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APPENDIX A

FINAL SURVEY

1. Rate on a basis 1 to 10 how much you have improved and/or developed the following skills:

• organization	(not so much)	1 2 3 4 5 6 7 8 9 10	(very much)
• problem solving		1 2 3 4 5 6 7 8 9 10	
• logical thinking		1 2 3 4 5 6 7 8 9 10	
• mathematical thinking		1 2 3 4 5 6 7 8 9 10	
• reorganization of ideas		1 2 3 4 5 6 7 8 9 10	
• transfer acquired scientific knowledge to new situations		1 2 3 4 5 6 7 8 9 10	
• support your own ideas		1 2 3 4 5 6 7 8 9 10	
• self confidence - "risk taking in solving problems		1 2 3 4 5 6 7 8 9 10	
• recognize flaws in your own hypotheses		1 2 3 4 5 6 7 8 9 10	
• using your mistakes as valuable tools for your intellectual and personal improvement		1 2 3 4 5 6 7 8 9 10	

2. Critical thinking is a very broad category. Some of the skills required to be a good critical thinker were cited above. How do you rate yourself as a critical thinker on a basis 1 to 10?

(not so good) 1 2 3 4 5 6 7 8 9 10 (very good)

3. Would you like to add one or more skills to the above list for being a good critical thinker?

( ) yes ( ) no

If yes, what is(are) it (them)? ______________________________

____

____

____

____

4. Do you believe concept mapping has improved your critical thinking? Could you please rate its usefulness on a basis 1 to 10?

(not so much) 1 2 3 4 5 6 7 8 9 10 (very much)

5. Is this the first time you have made a concept mapping diagram?

( ) yes ( ) no

If no, when and where you worked with concept mapping? ____________________

____

____

6. Would you think the concept mapping had been more useful if the purpose of it had been explained to you at the beginning of the Program?

( ) yes ( ) no

7. Did you hand in the final assignment about concept mapping (problem set #7)?

( ) yes ( ) no

If no, could you please list the reason(s) why not? ____________________

____

____

____

____

8. Briefly explain how the concept mapping helped or did not help your understanding in Physics.

____

____

____

____

9. Rate on a basis of 1 to 10 how much of the elements listed below helped you to:
(a) identify misconceptions in Physics
(b) resolve your misconceptions in Physics

• lectures	(not so much)	1 2 3 4 5 6 7 8 9 10	(very much)
• tutorials		1 2 3 4 5 6 7 8 9 10	
• problem sets		1 2 3 4 5 6 7 8 9 10	
• lab		1 2 3 4 5 6 7 8 9 10	
• concept mapping		1 2 3 4 5 6 7 8 9 10	

• inventing homework problem 1 2 3 4 5 6 7 8 9 10

• textbook 1 2 3 4 5 6 7 8 9 10

• exams 1 2 3 4 5 6 7 8 9 10

• intuition test 1 2 3 4 5 6 7 8 9 10

10. Do you feel you still have major misconceptions which have remained unresolved about material covered in the course?

( ) yes ( ) no

If so, what are those misconceptions? ______________________________

____

____

____

____

____

____

11. Do you think your worldview has altered after resolving the misconceptions in the topics covered in this Project? To what extent?

(not so much) 1 2 3 4 5 6 7 8 9 10 (very much)

Could you please give one example? ______________________________

____

____

____

____

____

12. Do you believe those misconceptions have played an important role in terms of your academic perfomance in this Project?

(not so much) 1 2 3 4 5 6 7 8 9 10 (very much)

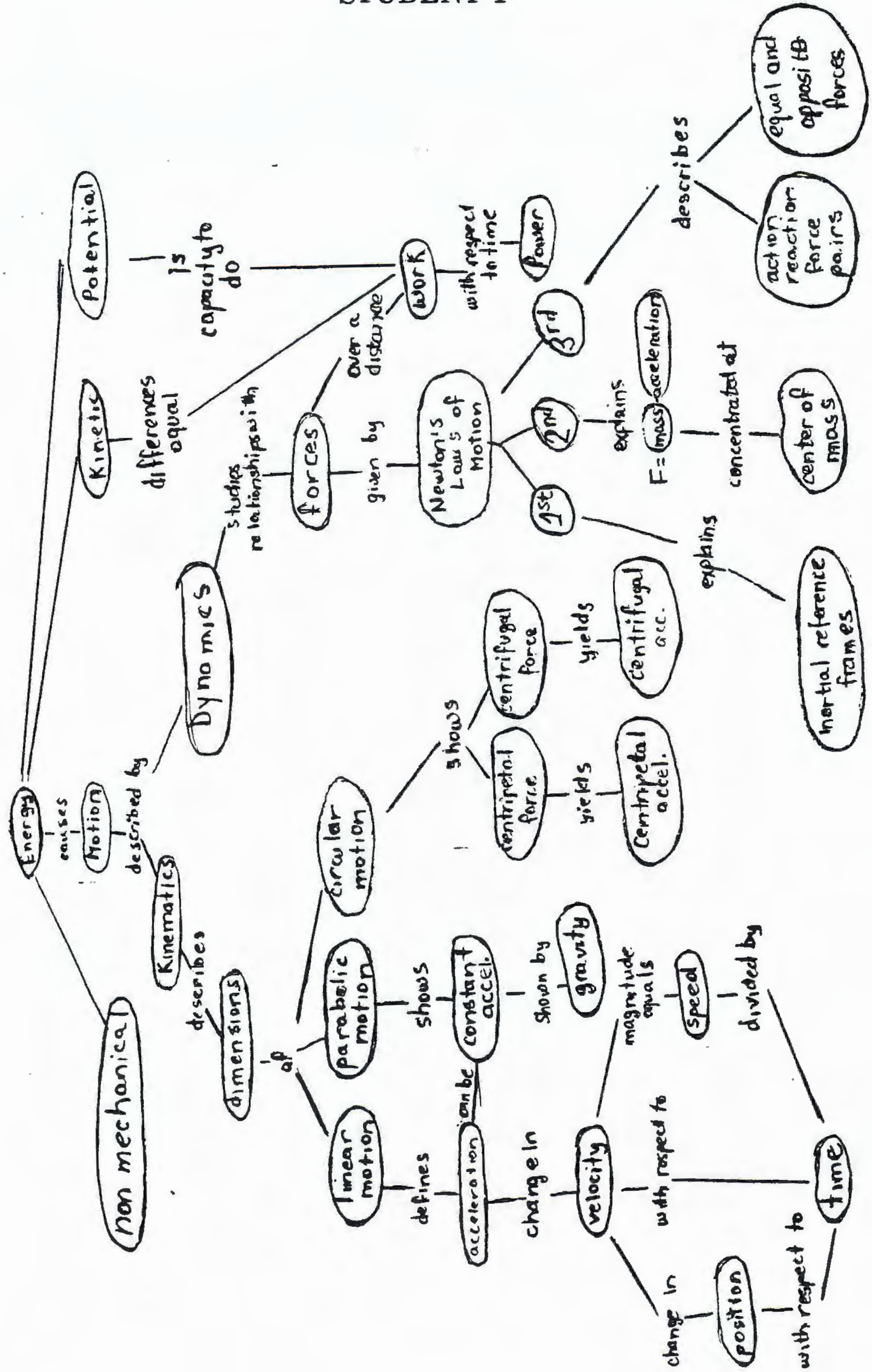
13. Have you had a chance to discuss your misconceptions in elementary and/or high school science classes?

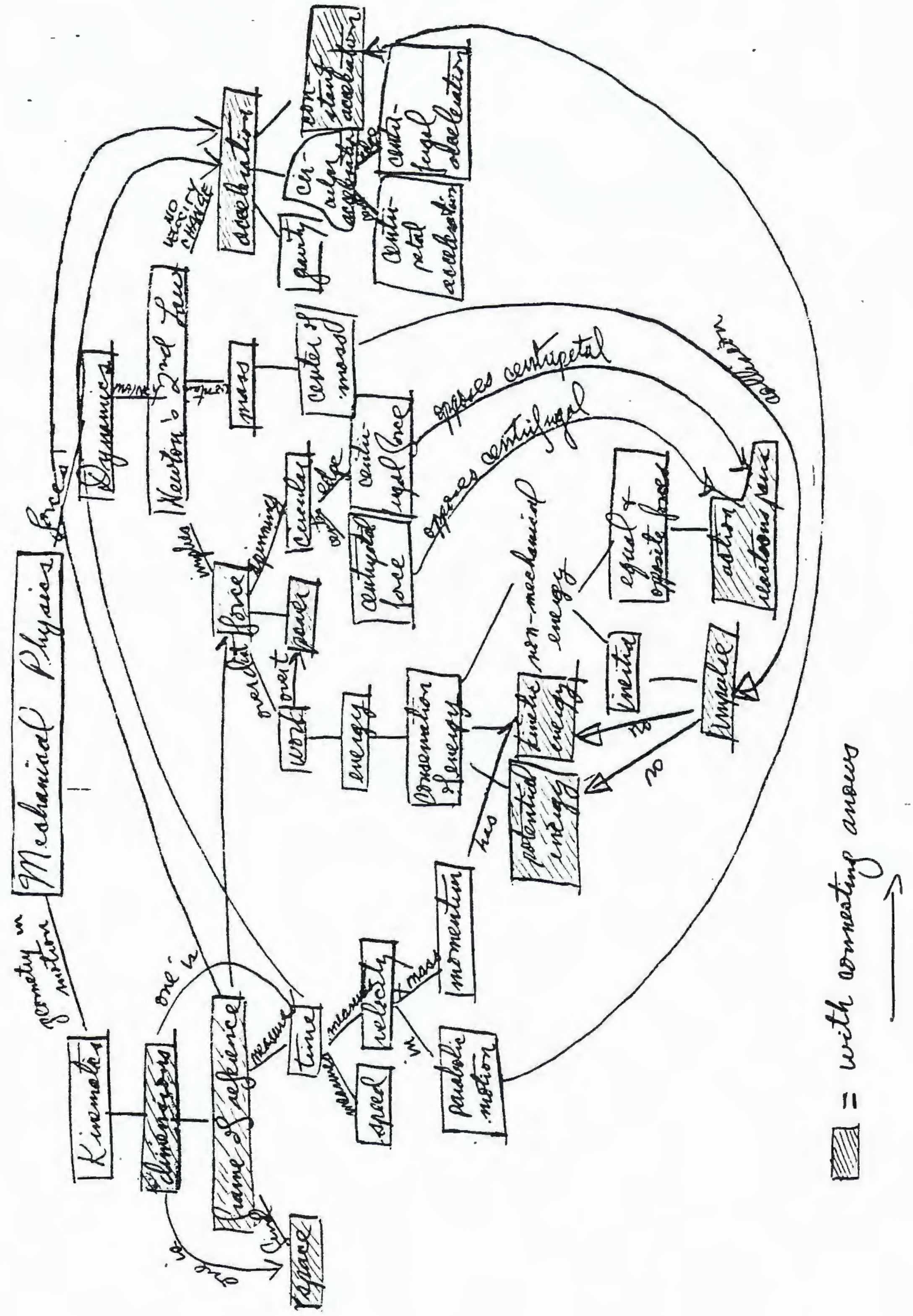
( ) yes ( ) no

Thank you!

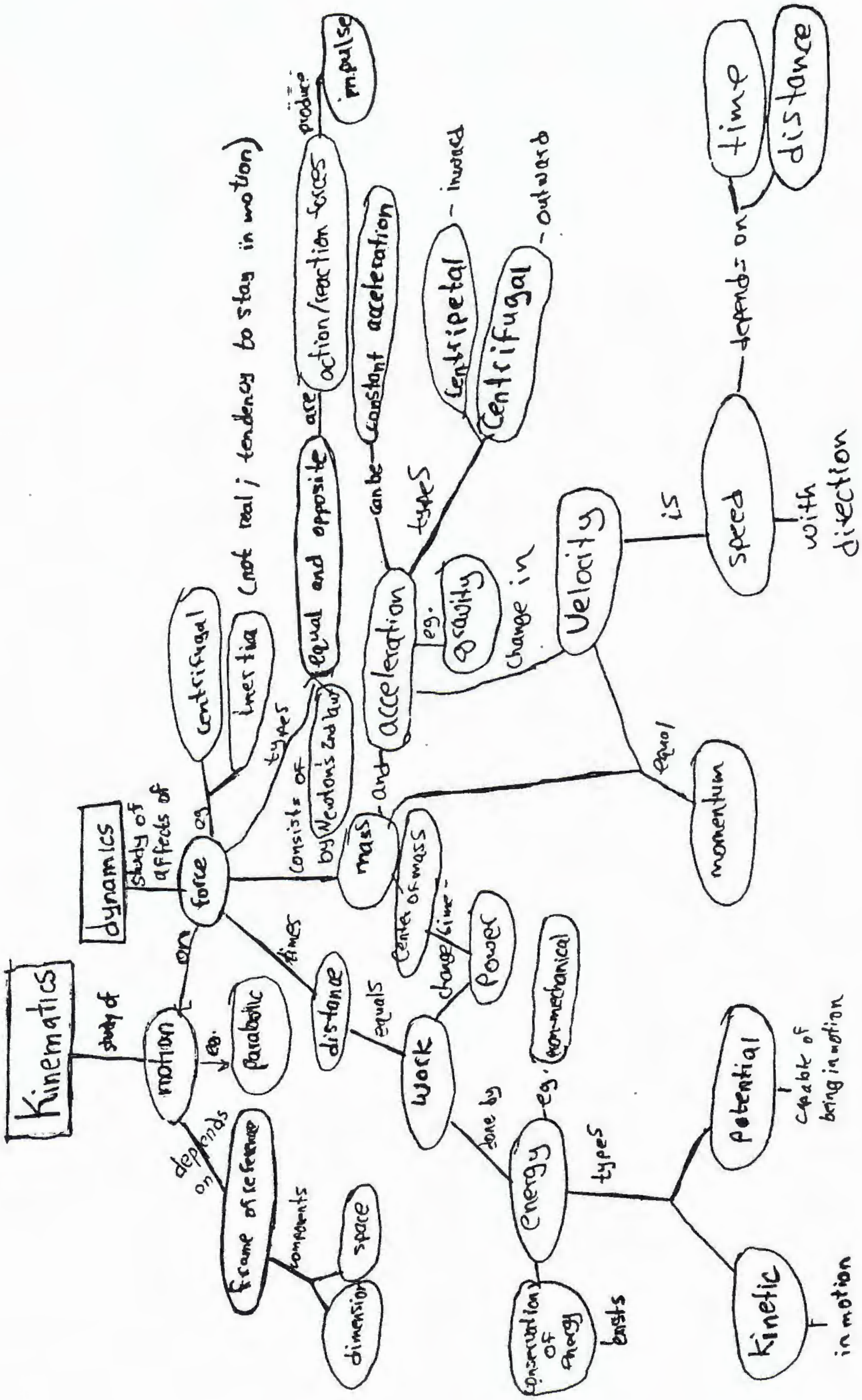
APPENDIX B

STUDENTS' CONCEPT MAPS USING CONCEPTS IN MECHANICS
STUDENT 1




Mechanical Physics
Kinematics
Dynamics
Newton's 2nd Law
mass
center of mass
acceleration
force
power
work
energy
conservation of energy
kinetic energy
potential energy
non-mechanical energy
momentum
velocity
speed
time
frame of reference
space
dimensions
parabolic motion
impulse
inertia
equal & opposite force
action reaction pair
centripetal force
centrifugal force
centripetal acceleration
centrifugal acceleration
gravity
opposes centripetal
opposes centrifugal
forces
geometry in motion
= with connecting arrows

STUDENT 3


Kinematics
study of
motion
eg.
Parabolic
depends on
Frame of reference
components
space
dimension
on
dynamics
study of affects of
force
eg.
Centrifugal
Inertia
(not real; tendency to stay in motion)
types
Equal and opposite
are
action/reaction forces
produce
impulse
consists of
by Newton's 2nd law
mass
and
acceleration
can be
constant acceleration
types
Centripetal
inward
Centrifugal
outward
eg.
gravity
change in
Velocity
is
speed
with direction
depends on
time
distance
equal
momentum
times
distance
equals
work
Center of mass
change
time
Power
done by
energy
eg.
non-mechanical
types
Potential
capable of bring in motion
Kinetic
in motion
Conservation of Energy
exists